PB-237 117

APPLYING FABRIC FILTRATION TO COAL FIRED INDUSTRIAL BOILERS. A PRELIMINARY PILOT SCALE INVESTIGATION

John D. McKenna

Enviro-Systems and Research Incorporated

Prepared for:

National Environmental Research Center

July 1974

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TECHNICAL REPORT DATA
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1. REPORT NO. EPA-650/2-74-058	2.
3.	PB 237 117
4. TITLE AND SUBTITLE: Applying Fabric Filtration to Coal Fired Industrial Boilers (A Preliminary Pilot Scale Investigation)	5. REPORT DATE: July 1974
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S): John D. McKenna	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Enviro-Systems and Research, Inc. P. O. Box 658 Roanoke, Virginia 24004	10. PROGRAM ELEMENT NO. 1AB012; ROAP 21ADJ-038
	11. CONTRACT/GRANT NO. 68-02-1093
12. SPONSORING AGENCY NAME AND ADDRESS: EPA, Office of Research and Development, NERC-RTP Control Systems Laboratory, Research Triangle Park, NC; Enviro-Systems and Research, Inc.; and Kerr Industries, Concord, NC	13. TYPE OF REPORT AND PERIOD COVERED: Final
	14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES	

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16. ABSTRACT: The report gives results of a preliminary pilot-scale investigation to determine the techno-economic feasibility of applying a fabric filter dust collector to coal-fired industrial boilers. The pilot facility, on a slipstream of a 60,000 lb/hr boiler, was capable of handling 11,000 acfm at an air-to-cloth ratio (A/C) of 6/1. Filter media evaluated include Nomex felt, Teflon woven, Teflon felt, and Gore-Tex laminate. Overall efficiencies greater than 99.5% were achieved with Nomex felt at an A/C of 6/1. Cleaning of Nomex felt bags improved with increasing volumes of reverse air. The Nomex felt bags deteriorated. Both woven Teflon and Gore-Tex on Nomex backing had better release properties than Nomex felt. Installed costs for a fabric filter capable of handling 70,000 acfm and using Nomex felt at A/C of 4.3, 6.3, and 7.5 were $164,000, $141,700, and $104,000 ($/acfm costs are $2.34, $2.02, and $1.48). Installed costs for other filter media as well as electrostatic precipitation (ESP) at three levels of efficiency are presented. Operating and annualized costs were also determined and compared to those for an ESP. Based on 25% bag replacement per year and an ESP efficiency level of 98%, Nomex felt and Gore-Tex on Nomex backing are competitive with ESP at A/C greater than 4/1. A/C must be greater than 7/1 before Teflon felt becomes competitive. Another report is planned.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution	Boilers	Air Pollution Control	13B
Filtration	Dust Collectors	Stationary Sources	07D
Filter Materials	Feasibility	Fabric Filters	13K, 14A
Coal	Tetrafluoroethylene Resins	Nomex	21D
Combustion		Teflon	21B, 11I
Industrial Heating		Gore-Tex	13A

18. DISTRIBUTION STATEMENT: Unlimited	19. SECURITY CLASS (This Report): Unclassified	21. NO. OF PAGES: 90
	20. SECURITY CLASS (This page): Unclassified	22. PRICE: 4.75

EPA Form 2220-1 (9-73)

EPA-650/2-74-058

APPLYING FABRIC FILTRATION TO COAL FIRED INDUSTRIAL BOILERS

A PRELIMINARY PILOT SCALE INVESTIGATION

by

John D. McKenna

Enviro-Systems and Research, Inc.
P. O. Box 658
Roanoke, Virginia 24004

Contract No. 68-02-1093
ROAP No. 21ADJ-038
Program Element No. 1AB012

EPA Project Officer: James H. Turner

Control Systems Laboratory
National Environmental Research Center
Research Triangle Park, North Carolina 27711

Prepared for

OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

July 1974

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This report has been reviewed by the Environmental Protection Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

ABSTRACT

A preliminary pilot scale investigation was conducted to determine the techno-economic feasibility of applying a fabric filter dust collector to coal fired industrial boilers. The pilot facility, installed on a slip stream of a 60,000 lb/hr. boiler, was sized to handle 11,000 ACFM when operating at an air-to-cloth ratio of 6/1. Filter media evaluated included Nomex felt, Teflon woven, Teflon felt and Gore-Tex laminate.

Overall efficiencies greater than 99.5% were achieved with Nomex felt at an air-to-cloth (A/C) ratio of six to one. Cleaning of Nomex felt bags was found to improve with increasing volumes of reverse air. Deterioration of the Nomex felt bags was observed. Both woven Teflon and Gore-Tex on Nomex backing were found to have better release properties than Nomex felt.

Installed costs for a fabric filter capable of handling 70,000 ACFM and employing Nomex felt at A/C of 4.3, 6.3 and 7.5 were found to be $2.34, $2.02 and $1.48/ACFM. Installed operating and annualized costs for other filter media as well as electrostatic precipitation at three levels of efficiency are presented. Based on 25% bag replacement per year and an electrostatic precipitator (ESP) efficiency level of 98%, Nomex felt and Gore-Tex on Nomex backing are competitive with ESP at A/C greater than 4/1. Teflon felt needs to be employed at A/C greater than 7/1 before it becomes competitive.

A follow-on program has been initiated to confirm the results of this initial investigation and to expand the data obtained.

This report was submitted by Enviro-Systems & Research, Inc., Roanoke, Virginia, in fulfillment of Contract No. 68-02-1093 under the joint sponsorship of Enviro-Systems & Research, Inc., Kerr Industries and the Environmental Protection Agency.

CONTENTS

		Page
List of Tables		iv
List of Figures		v
Acknowledgements		vi
Sections		
I	Introduction	1
II	Conclusions	2
III	Recommendations	4
IV	Program Description	6
V	Data Obtained	13
VI	Economics	30
VII	References	44
VIII	Appendices	45

Tables

Table No.	Title	Page
1	Outlet Loadings at Different Air-to-Cloth Ratios	23
2	Dust Removal Efficiencies	27
3	Data Summary of Nomex Felt Post Run Analysis	28
4	Fabric Filter Unit Size vs. Air-to-Cloth Ratio	32
5	Electrostatic Precipitator Purchase Cost Basis	37
6	Annual Fuel Cost	42
A-1	Filter Media Characteristics	47
A-2	Pilot Plant Flow Data	48

Figures

Figure Numbers	Title	Page
1	Schematic Diagram	8
2	General Arrangement Drawing	9
3	Pilot Plant Photo	12
4	Comparison of Nomex Felt and Gore-Tex Pressure Drop Profiles	14
5	Pilot Plant Plan View Showing Cell Identification	17
6	Variation in Cleaning Duration	18
7	Variation in Reverse Air Volume	19
8	Variation in Reverse Air Volume	20
9	Inlet Particle Size Distribution	22
10	Comparison of Laboratory and In-Situ Particle Size Distribution	24
11	Outlet Particle Size Distribution A/C = 6	25
12	Outlet Particle Size Distribution A/C = 3	26
13	Installed Cost vs. Air-to-Cloth Ratio - Nomex Felt	31
14	Installed Cost vs. Air-to-Cloth Ratio - Teflon Felt	33
15	Installed Cost vs. Air-to-Cloth Ratio - Gore-Tex on Nomex Backing	35
16	Installed Cost vs. Air-to-Cloth Ratio - Case Comparisons	36
17	Installed Costs vs. Efficiency - Electrostatic Precipitator	39
18	Annual Operating Costs vs. Air-to-Cloth Ratio	40
19	Annualized Costs vs. Air-to-Cloth Ratio	41
A-1	Performance of Gore-Tex Filter Bags	50
A-2	Performance of Gore-Tex Filter Bags	51

ACKNOWLEDGEMENTS

This program was jointly sponsored by the Federal Environmental Protection Agency, Kerr Industries and Enviro-Systems & Research, Inc.

Gore-Tex bags were donated to the program by W. L. Gore & Associates. Woven Teflon material was donated to the program by E. I. duPont.

In-situ particle size and sulfur oxide measurements were performed by EPA personnel.

The author wishes to express his deep appreciation for all of the foregoing contributions and in particular thank the following people for their assistance: Mr. Fred L. Trull and Mr. Sidney Perry of Kerr Industries, Concord, North Carolina, Dr. James Turner and Mr. Bruce Harris of EPA, Research Triangle Park, North Carolina, Mr. Edward deGarbolewski of W. L. Gore & Associates, Elkton, Maryland and Mr. Joseph A. Genereux and Dr. H. H. Forsten of E. I. duPont de Nemours & Company, Wilmington, Delaware.

INTRODUCTION

Industrial boilers consume more than 100 million tons of coal per year resulting in a potential emission of more than 2.5 million tons of fly ash annually.[1] Historically, the method of emission control employed has been some variation of the cyclone type dust collector. The purpose of the subject study was to conduct a preliminary evaluation of the feasibility of applying fabric filter dust collection to industrial size coal fired boilers. In order to conduct such an evaluation, a fabric filter pilot plant was installed on a slip stream of a stoker boiler stack. While a limited number of fabric filter installations[2,3] have been attempted on coal and oil fired utility boilers, little or no data has been published for similar attempts on industrial size boilers.

Borgwardt[4] and his co-workers collected data on the operation of a pilot baghouse filtering flue gas from a pulverized coal-fired power plant with the goal of answering one question: "Is the particulate from coal burning power plant amenable to collection in a fabric filter system that maintains reasonable pressure drop and is not excessively large?" Similarly, the primary objective of this present study was to determine the techno-economic feasibility of applying a fabric filter dust collector to industrial boilers. Included in the scope of this preliminary feasibility analysis was the screening of a number of filter bag materials. For as Borgwardt noted, "the nature of the underlying fabric is the most important factor to be optimized to reduce total resistance of the filtering medium and deposited dust cake."

CONCLUSIONS

The data obtained is very limited and does not lend itself to extensive analysis. A number of preliminary conclusions can be drawn. These conclusions are limited to the case under consideration, that is a stoker fed industrial boiler burning low sulfur coal. In all cases, there is a need to confirm these conclusions.

Firstly, when Nomex felt is employed overall efficiencies greater than ninety-nine and one-half percent are achievable even at air-to-cloth ratios of six to one. Increasing the air-to-cloth ratio does increase the outlet dust loading.

An increase in the amount of air used for cleaning improves the cleaning of the Nomex felt bags.

An increase in the duration of cleaning above half a minute does not improve cleaning of Nomex felt.

Nomex felt does deteriorate rapidly when exposed to this flue gas. Continuous feeding of lime into the inlet gas stream may reduce the rate of deterioration.

Both woven Teflon and Gore-Tex on Nomex backing have better release properties than Nomex felt, and both woven Teflon and Gore-Tex are incompatable with the original pilot plant hardware arrangement.

For the size industrial boiler studied, both Nomex felt and Gore-Tex on Nomex backing are competitive with electrostatic precipitation at air-to-cloth ratios greater than about four to one. On a basis of 25% bag replacement per year and an electrostatic precipitator efficiency level of 98%, Teflon felt needs to be employed at an air-

to-cloth ratio greater than about seven to one before it becomes competitive with electrostatic precipitation.

Preheating the dust collector inlet gas does not appear economically feasible.

A follow-on program has been initiated. This second program is aimed at confirmation of the above conclusions and expansion of the data obtained.

RECOMMENDATIONS

Based upon the preliminary results obtained, both in terms of the operational data and economic feasibility, it appears worthwhile to pursue the study further.

The following areas are recommended for additional study:

1. Develop a family of curves of pressure drop across the bags vs. air-to-cloth ratio for three levels of reverse air for Nomex felt. Additional study on Nomex felt is needed to confirm preliminary bag life results and extend the data obtained.
2. Develop a family of curves of pressure drop across the bags vs. air-to-cloth ratio for three levels of reverse air for Teflon felt.
3. Develop a family of curves of pressure drop across the bags vs. air-to-cloth ratio for three levels of reverse air for Gore-Tex on Nomex backing.
4. Develop relationships between reverse air volume, air-to-cloth ratio and outlet loadings.
5. Develop baghouse capital and oeprating costs for the cloths studied which meet existing emission codes.
6. Develop relationships between reverse air duration for less than 30 seconds and pressure drop across the bags.

In order to execute studies of Gore-Tex, it will be necessary to employ a rigid cage and also to secure each bag so that it cannot swing.

The first cut of the capital cost for woven Teflon utilizing a shaker as opposed to reverse air was not too encougaging. It does

appear that tests should be made to determine removal efficiencies at an air-to-cloth of about two or three and if these appear satisfactory then preliminary economics should be run on a reverse air system.

An assessment of how representative the boiler being tested is needs to be made. This will allow expansion of the techno-economic evaluation to a more comprehensive basis. In this regard the influence of boiler size on annualized costs needs to be developed.

Based upon the temperature profile obtained at Kerr it does appear that Dralon T felt (homopolymer acrylic) can be incorporated into the study.

A study of the influence of continuous injection of lime on bag life, in particular Nomex felt, is also recommended.

PROGRAM DESCRIPTION

Introduction

A fabric filter pilot unit capable of handling 11,000 ACFM of flue gas when operating at an air-to-cloth ratio of 6/1 was installed on a coal fired industrial boiler at Kerr Industries in Concord, North Carolina. Installation was accomplished during July with start-up early in August, 1973.

While it has been demonstrated that fabric filter (baghouse) dust collectors can be applied to fly ash removal, there was a need for a techno-economic evaluation of fabric filters as specifically applied to industrial size coal fired boilers. There have been some recent developments in bag technology which may affect application problems previously encountered by others and the economics of fabric filters applied to fly ash removal.

Purpose

The purpose of the subject program was to conduct a preliminary techno-economic evaluation of the application of fabric filter dust collection to coal fired industrial boilers.

Scope

The scope of this program was to perform experiments with the fabric filter pilot unit in order to:

1. Determine the feasibility of using Teflon bags to eliminate acid dew point - bag life problems.
2. Determine performance of expanded Teflon coated bags.
3. Determine optimum operating condition of the reverse air cleaning method.

4. Provide K value data for fly-ash applications.

5. Provide data for an economic comparison of ESP versus fabric filtration for fly ash removal.

6. Provide data for a techno-economic evaluation of direct fired heating as a method to avoid acid dew point - bag life problems.

7. Provide data for comparisons of the performance of different filter fabrics.

8. Provide description of fabric characteristics before and after exposure to flue gases.

9. Provide data on the flue gas dust particle characteristics.

10. Provide data on the characteristics of the flue gas.

Pilot Plant Description

The fabric filter or baghouse pilot plant employed in this program is illustrated by Figure 1 - Schematic Diagram and Figure 2 - General Arrangement Drawing. The baghouse is subdivided into four separate cells. Each cell contains fifty-four bags. The bags are 5 inches in diameter and eight feet eight inches long. Each bag has 11.5 $ft.^2$ of cloth giving 620 $ft.^2$ of cloth per cell and 2,480 $ft.^2$ of cloth for the house. The bags are set into the tube sheet, located approximately 13" from the top of the house, by the use of two snap rings incorporated into the bag itself. The snap rings lock in place one above and one below the tube sheet. A spiral cage is set inside the bag and keeps the bag from collapsing. The dirty gases enter one end of the unit, pass through the tapered duct, into the classifier, then through the bags. The classifier forces the dirty gases to change direction 90°, then 180°. This quick directional change forces the larger and heavier particles out of the flow so that they fall directly into the hopper. Dirty gases enter the classifier thru a central duct which is tapered to feed the same quantity of gas into each of the four cells. The

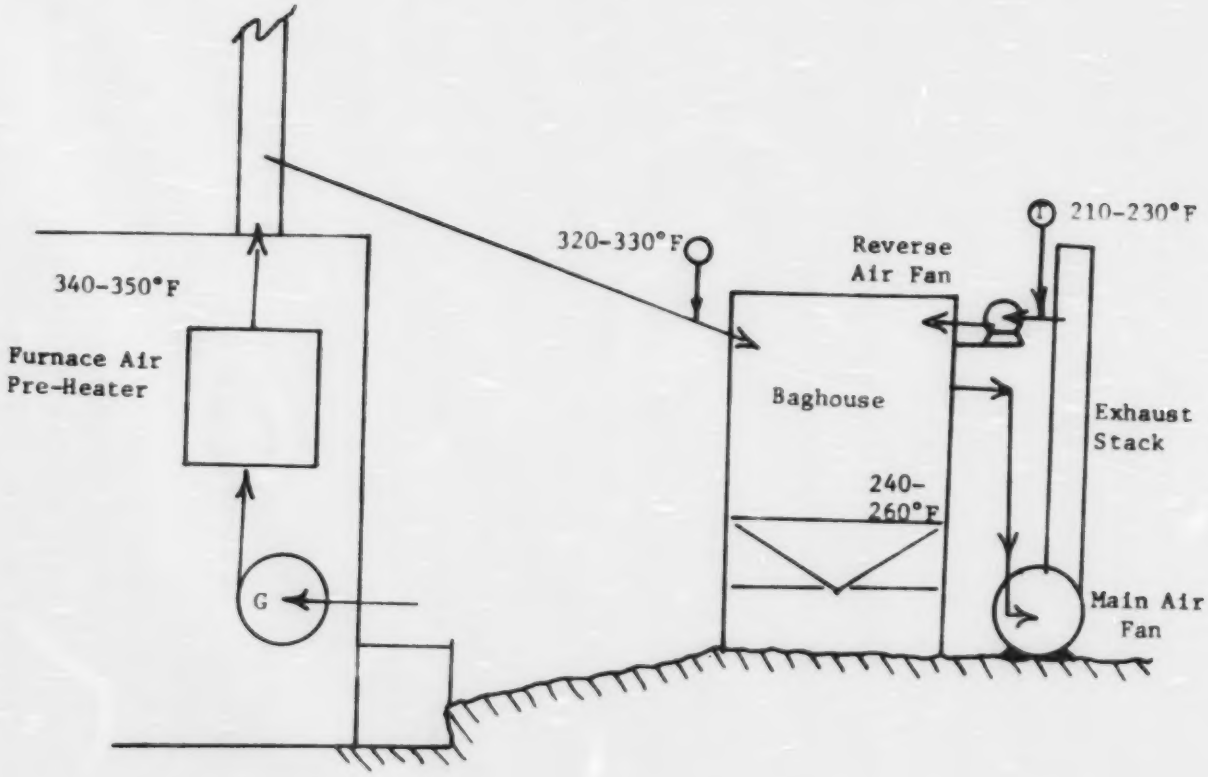


Figure 1

Pilot Plant
Schematic Diagram with Temperature Profile

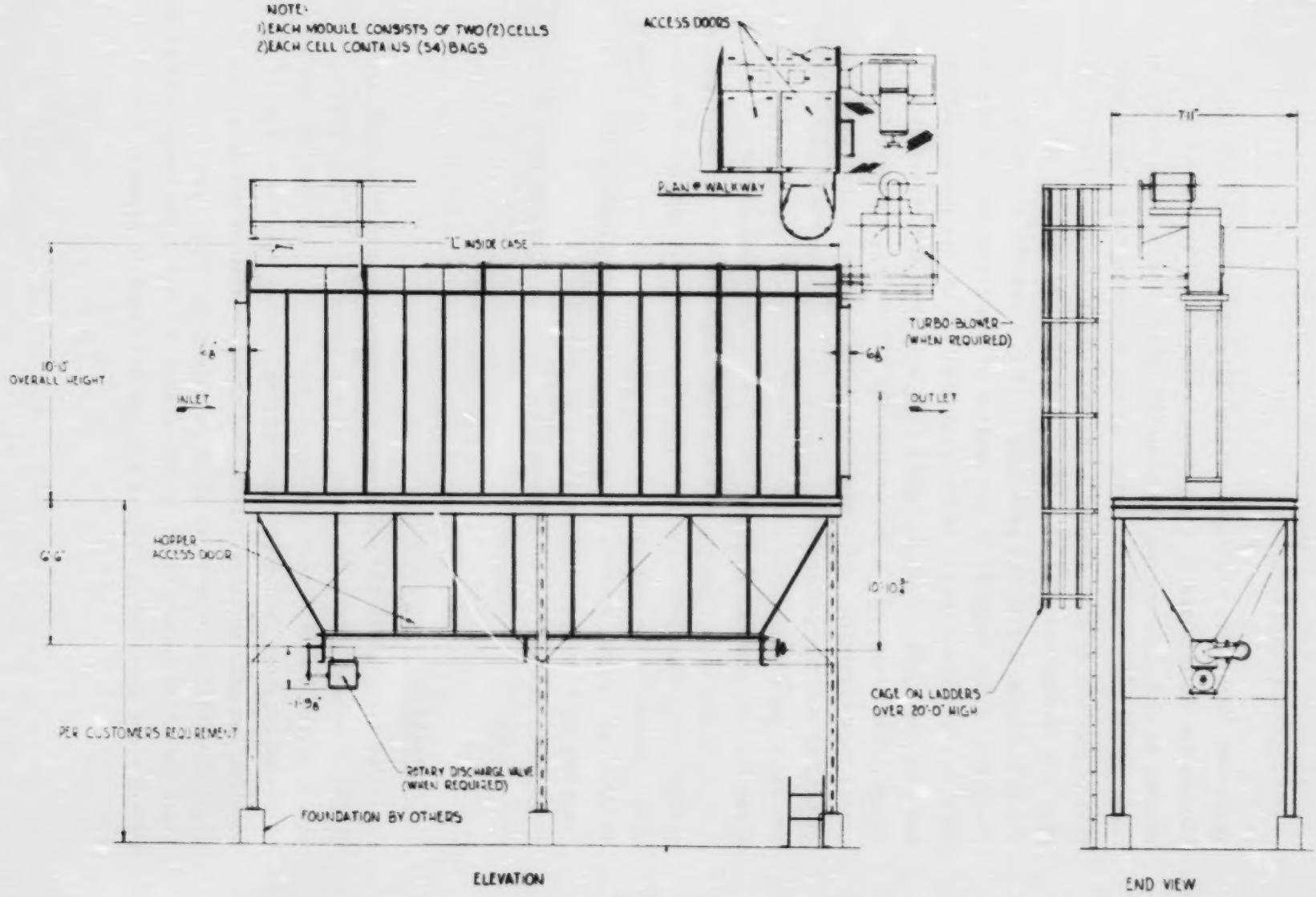


Figure 2

General Arrangement Drawing

gases are forced thru the fabric filter into the center of the bags, leaving the particulate on the outer surface of the bags where it is removed periodically during the cleaning cycle. The cleaned gases are drawn up and out through the center of the filtering bag into a center exit plenum via an open damper in the cell above the tube sheet. The bags are cleaned one cell at a time by closing off the cell damper to the exit plenum and at the same time opening a reverse air damper. As the solid matter collects on the outside of the filter bag, it builds a cake or crust which begins to restrict the flow of the gases. During the cleaning cycle, clean air enters the cell thru the reverse air damper. The clean air is forced down the filter bag, opposite to the normal flow direction, which expands it with a shock so that the cake is cracked and the particulate falls off the bag into the hopper. After the shock has expanded the filter bag and broken off the cake, the clean air continues to flow providing a drag which pushes and pulls the dust particles away from the fabric. The smaller particles are thus forced out of the fabric and fall into the hopper for removal from the unit. Damper system and control panel arrangements allow for variations in main gas volume, reverse air volume, duration of cleaning and frequency of cleaning. The existance of four cells allows for repetitive sequential testing of different bag types without the need to change bags.

Filter Media Employed

Five types of filter media were considered as possible candidates in this program. These are Nomex felt - a polyamide, Teflon felt, Teflon woven, Dralon T felt - a homopolymer acrylic and Gore-Tex laminate - an expanded Teflon on Nomex backing. Bench results of the Gore-Tex laminate on Nomex backing had shown promise of higher air-to-cloth capabilities as well as quick release properties. The specifications for these materials are given in Appendix A-1. The bench results on Gore-Tex are provided in Figures A-1 and A-2 found in Appendix A-2.

Description of Kerr Industries Boilers

Two Babcock & Wilcox boilers are in operation at the Kerr facilities. Each has a design capacity of sixty thousand pounds of steam per hour and both are equipped with spreader stokers. Both boilers are equipped with fans for supplying draft and unit number two, the unit tapped for the pilot plant slip stream, has overfire steam injection for better combustion control. In January, 1973, emission tests had been conducted on these boilers. The particulate emission rates were found to be approximately 130 pounds/hour versus an allowable of about 25 pounds/hour. Gas volumes were determined to be about 35,000 ACFM at a temperature of about 355° F. Thus the grain loading measured was about 0.4 grains per ACFM. Orsat analysis indicated 9.5% CO_2, 10% O_2, 0% CO and 80.5% N_2. Coal analysis indicated the percent sulfur to be about 0.6%. Both the stack test report and the coal analysis report are provided in the Appendix.

Installation at Kerr

The pilot plant was installed on a slip stream from boiler number two at Kerr Industries - see Figure 3. The slip stream was 22" duct 40 feet long with a 90° elbow directed down into the gas flow of the Kerr boiler stack. A typical temperature profile is shown in Figure 1. The stack of boiler number two is about 350° F whereas the inlet to the baghouse is about 320° F and the outlet from the house is about 200° F. The reverse air used for cleaning the bags is taken from the pilot plant exhaust stack and this temperature was about 220° F. Both the slip stream duct and the pilot plant were uninsulated.

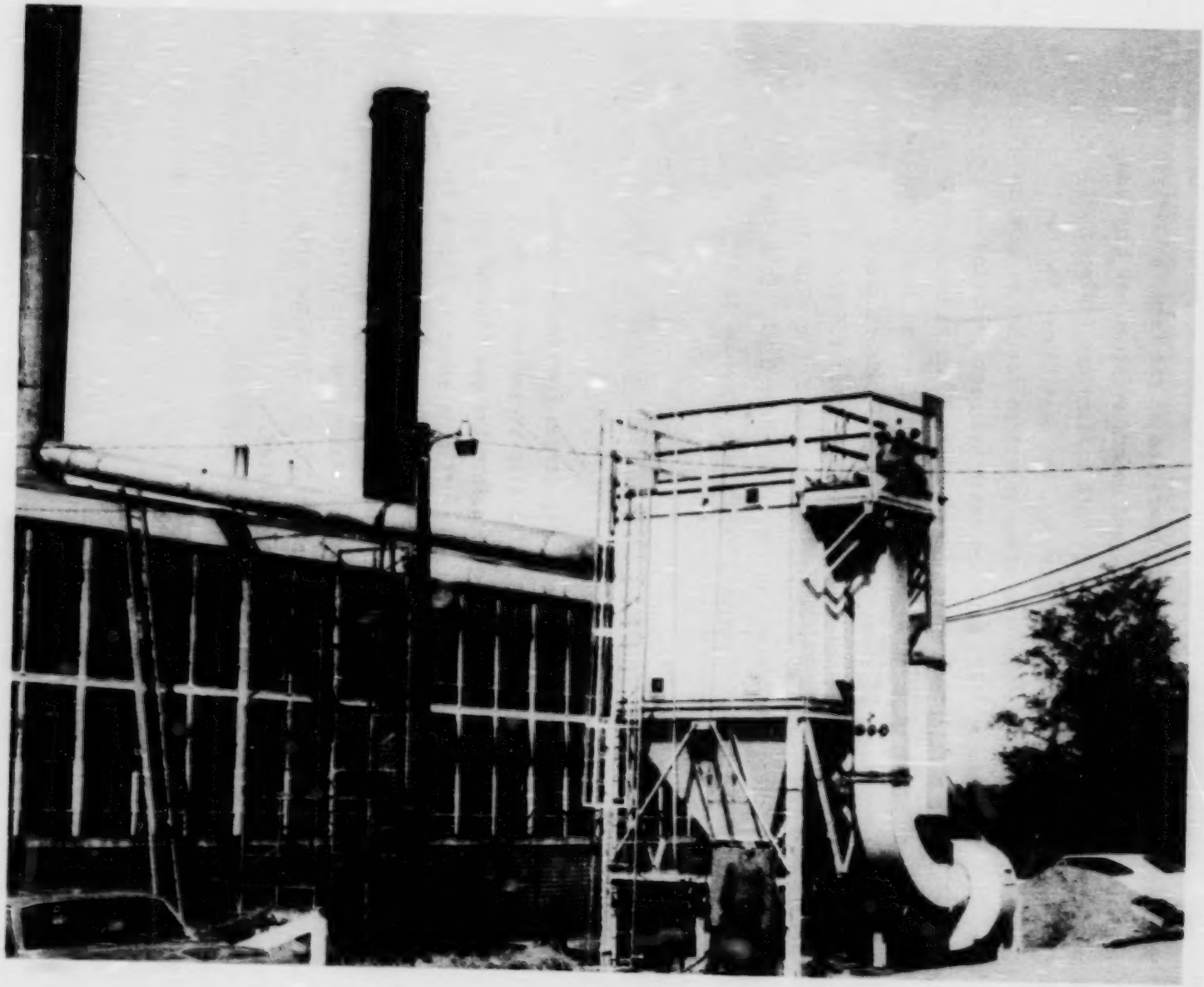


Figure 3
Fabric Filter Pilot Plant
Installed at Kerr

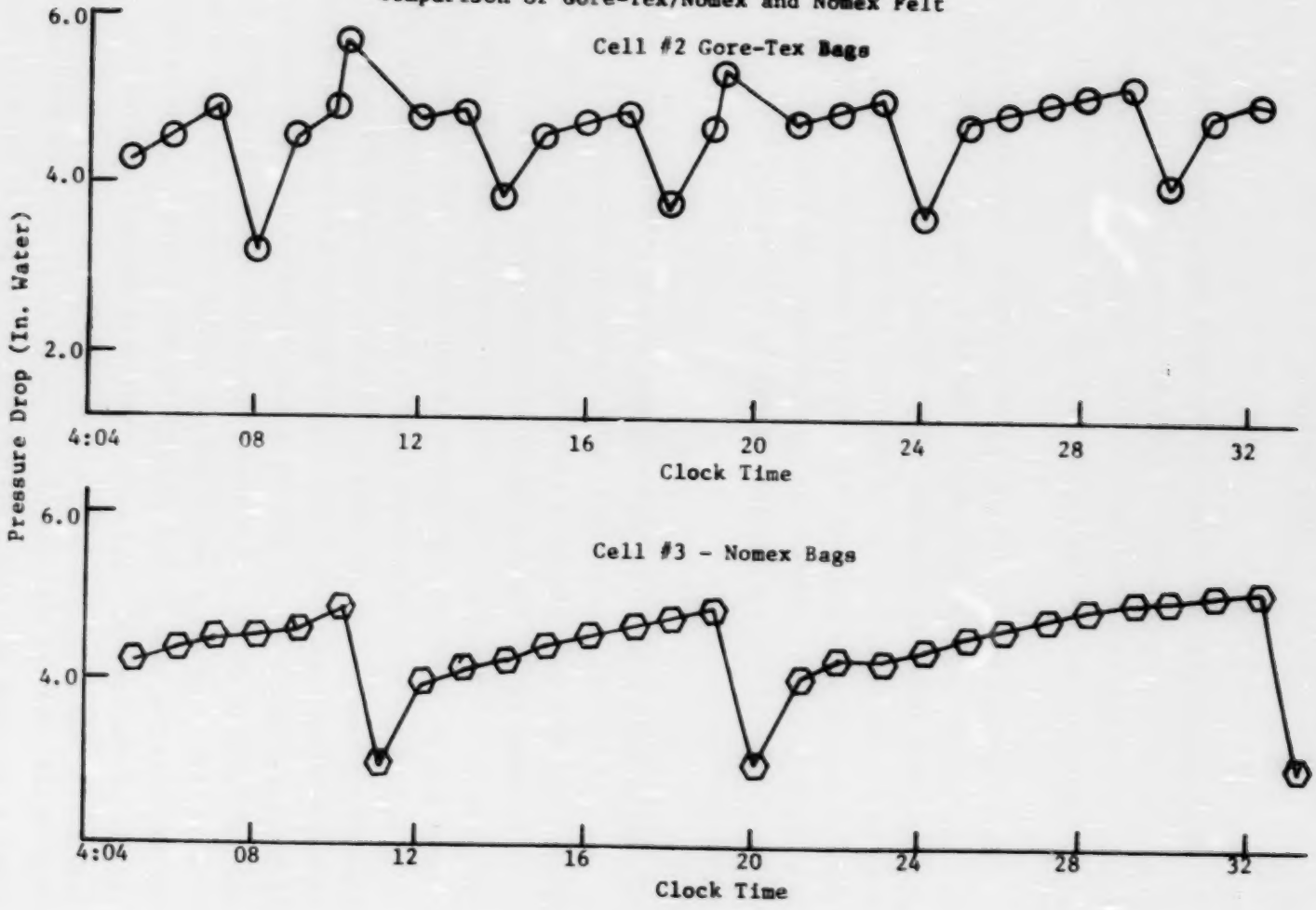
DATA OBTAINED

Pilot plant tests were conducted on Nomex felt, Gore-Tex and Teflon woven. Due to severe problems encountered in the use of light weight fabrics in conjunction with the pilot plant hardware the majority of the data obtained was secured when Nomex felt was the filter media.

Gore-Tex bags were in service briefly. First, two Gore-Tex bags were placed in a cell of Nomex bags. The first few days of operation indicated that these two bags had better release properties than the Nomex bags. The Gore-Tex bags consistently had about 1/32 of an inch layer of very friable dust over the entire surface with no evidence of dust pearling due to condensation. In contrast, the Nomex bags had a 1/4 inch layer of heavily pearled moderately friable dust over the entire surface.

After the two Gore-Tex bags had been in place for two weeks and had 20 hours of run time and probably eight dew point excursions, a full cell of Gore-Tex bags were placed in operation along with the original two cells of Nomex felt. The average air-to-cloth ratio was about 5/1 with the three cells in operation and about 8/1 when one cell was being cleaned and the other two cells were in operation. The flue gas volume delivered to the pilot plant was about 10,000 ACFM and the amount of cleaning or reverse air was about 3,000 ACFM. Gore-Tex pressure drop characteristics, both before and after cleaning, were found to be similar to the Nomex felt. Figure 4 shows a plot of both a cell of Nomex and a cell of Gore-Tex during simultaneous operation. Since three cells were in operation it is not known if the gas volume through the cell of Gore-Tex bags was the same as that through the Nomex felt. Due to early failure of the Gore-Tex bags very little data was obtained for this media. The day after the full cell of Gore-Tex bags was placed in operation it was observed that one of the two original Gore-Tex bags was torn. After a few hours on stream, all testing of the cell of Gore-Tex was

Figure 4
Comparison of Gore-Tex/Nomex and Nomex Felt



halted. Inspection of the cell of Gore-Tex bags showed that forty-four (44) of the fifty-four (54) bags had been damaged. Their total time on line was four hours. The Gore-Tex bags evidenced cracks, tears and seam thread rupture. Examination of the damaged Gore-Tex bags indicated mechanical damage due to flexing and cage movement as the principal cause of failure and further suggested increased woven backing thickness and rigid cages as a means of reducing failure. Tensile strength tests run on swatches of the damaged Gore-Tex bags indicated no change in tensile strength as compared to the original bags. This indicates that little or no uniform chemical attack took place.

After the Gore-Tex failure two fresh Gore-Tex bags were placed in operation, one lime coated and one uncoated. Both bags had rigid cages - that is the normal spring cage was braced with two vertical rods being welded into it in order to stop the bouncing action. The two Gore-Tex bags with braced cages were in service for thirty-five (35) hours of on stream time. At the end of this time no evidence of wear was observed.

Very little work was done with Teflon woven bags. No data was obtained other than a failure check. This test was conducted by placing three woven Teflon bags in service in a cell where the balance of the cell was filled with Nomex felt bags. One of the woven Teflon bags was placed on a rigidly braced cage and precoated with lime. A second Teflon bag was placed on an unbraced spring cage and this was also precoated. The third Teflon bag was placed in service on an unbraced cage without any precoating. After twenty-two (22) hours of service one of the bags with a free spring cage was severely damaged apparently due to frequent contact with the cell wall. At this time, the Teflon bag on the braced cage was also removed due to damage of the mounting ring. After thirty-five (35) hours on stream the third Teflon bag showed no significant wear. Regarding the release properties of the woven Teflon bags it was observed that these bags were in this respect equal to or slightly better than the Gore-Tex bags. A very thin cake was retained on the bag (in the order of 1/64 to 1/32 of an inch).

The majority of the experiments conducted were executed on two cells of Nomex felt bags. These bags were installed at the beginning of the program and almost all remained in place for the entire duration of the program. The cell designated #3, as shown in Figure 5, contained fifty-four (54) Nomex felt bags. These bags were soiled inadvertently prior to actual start-up. The cell designated #4 contained fifty-two Nomex bags and two Gore-Tex bags at the start of the program. All bags in cell #4 were precoated with lime prior to the initial start-up.

A number of parameters were studied with Nomex felt in service. These included the effect of duration, frequency and volume of cleaning air on clean-down and operating pressure drop. In addition, a test of the filtration efficiency at two levels of air-to-cloth ratios was undertaken and finally when the Nomex bags were removed from service laboratory analysis was conducted to determine if any filter media degradation had occurred.

Several tests were conducted on duration of cleaning time. These studies were made at one-half, one, two and three minutes duration and as shown in Figure 6, no improvement in the clean down pressure drop differential is obtained by increasing the duration of cleaning. The variations in pressure drop differential due to clean down seen here have been observed in other applications. One explanation of this could be changes in inlet loading.

Once it was determined that the bags had achieved equilibrium with respect to clean down pressure drop, a preliminary screening of the effect of the volume of reverse (cleaning) air upon the pressure drop was also conducted. The results are shown in Figures 7 and 8. It can be seen from these figures that an increase from 2,589 ACFM to 4,068 ACFM improved the clean down from a pressure drop reduction at clean down of 0.7 inches of water to about 1.5 inches. Since this was the limit of the reverse air fan capability it was decided to then block off half the bags in a cell to simulate the effect of further increasing the amount

Figure 5

Pilot Plant Plan View Showing Cell Identification

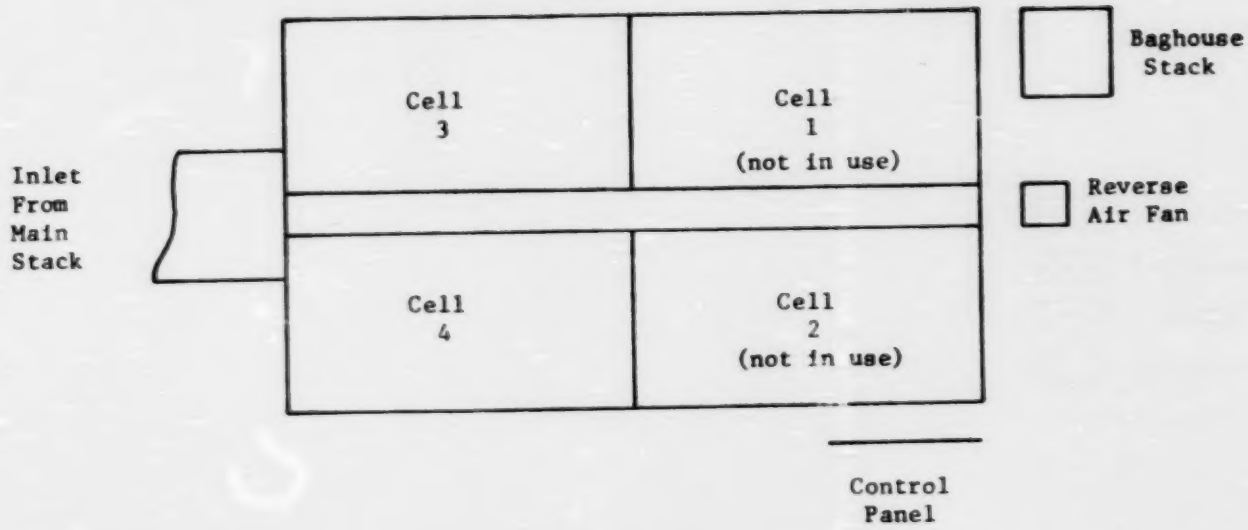


Figure 6

Variation in Cleaning Duration
Test Conducted on Nomex Felt

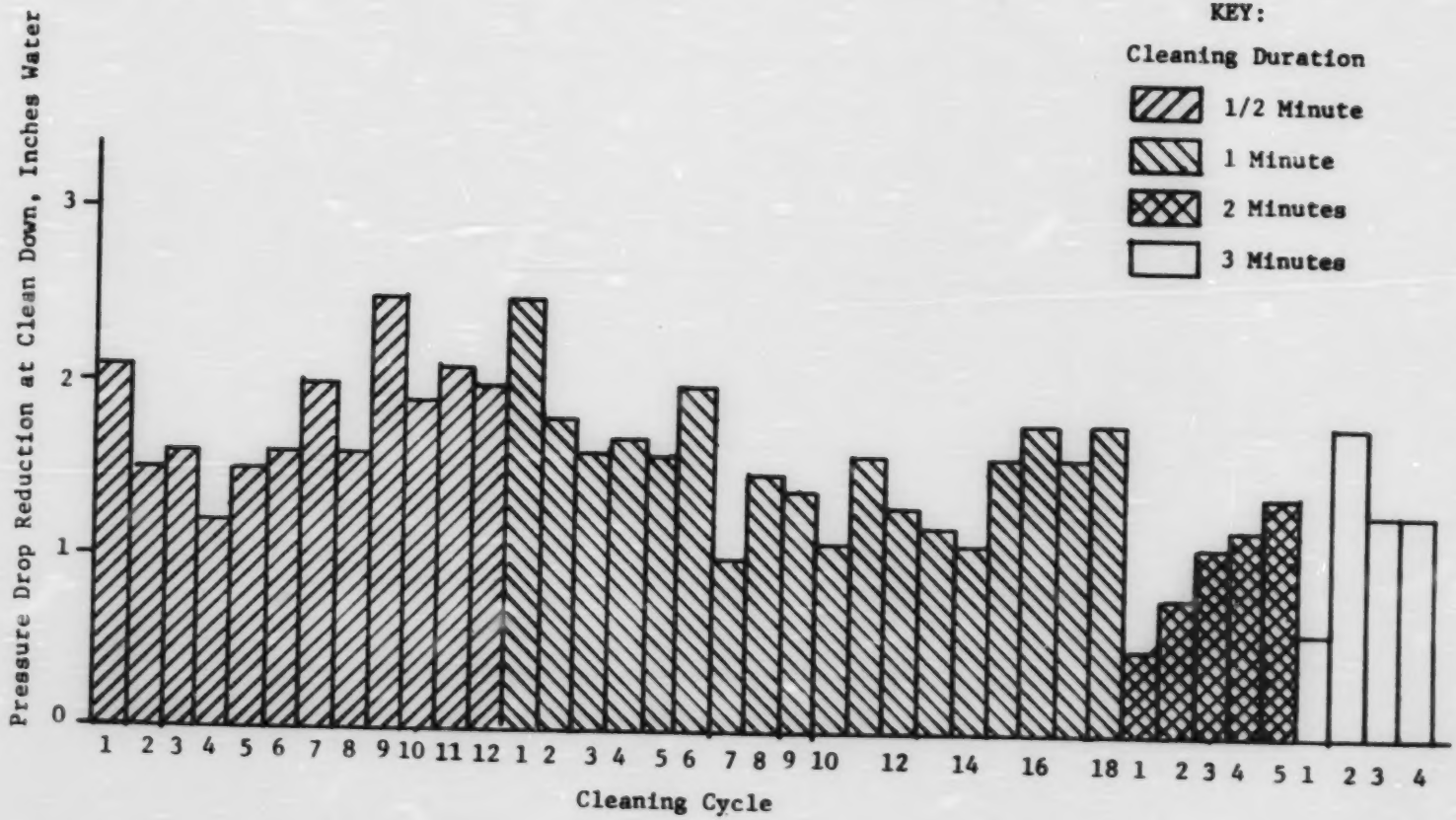

KEY:
Cleaning Duration
1/2 Minute
1 Minute
2 Minutes
3 Minutes
Pressure Drop Reduction at Clean Down, Inches Water
0
1
2
3
1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 12 14 16 18 1 2 3 4 5 1 2 3 4
Cleaning Cycle

Figure 7

Variation of Reverse Air Volume
Filter Media - Nomex Felt

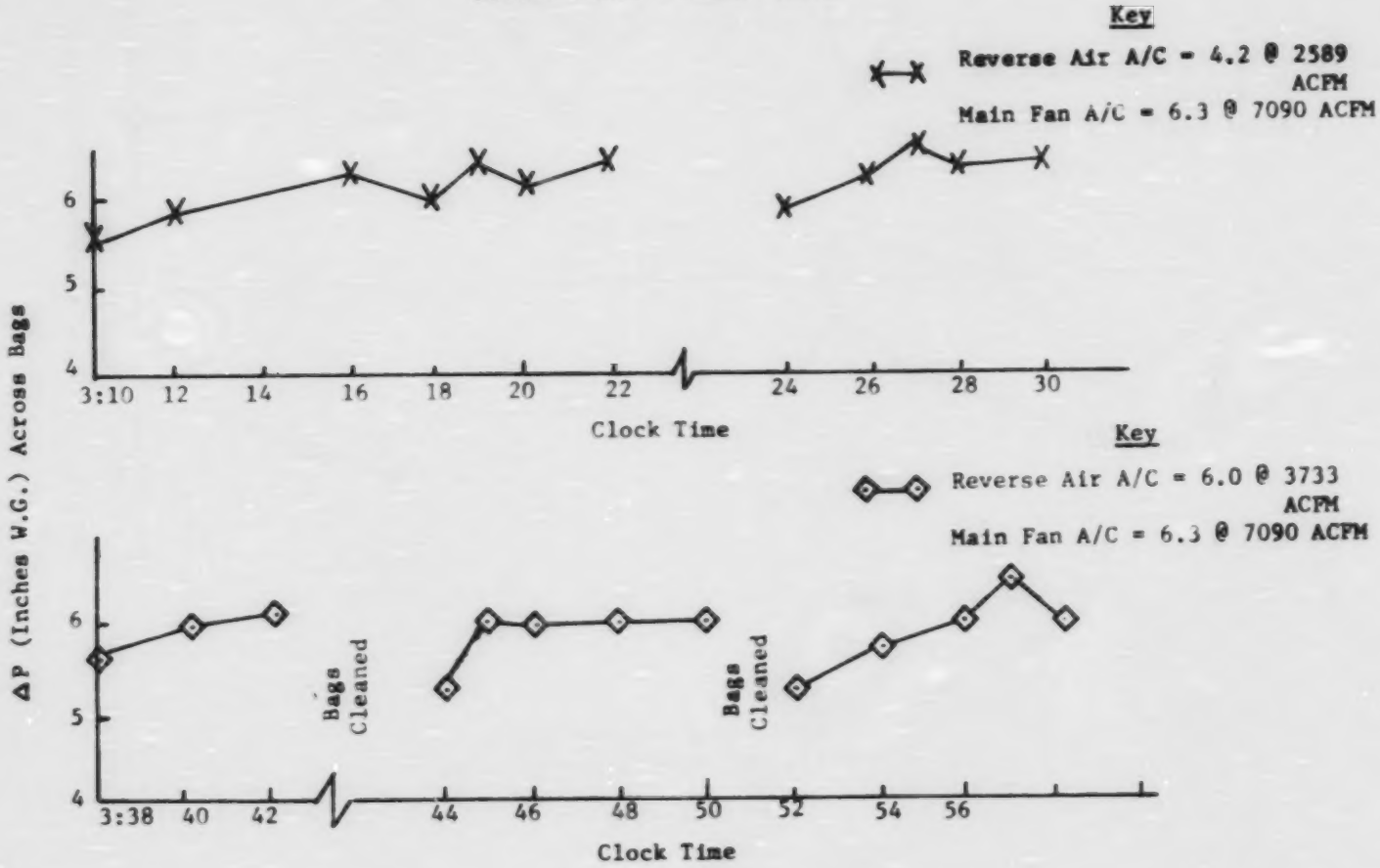
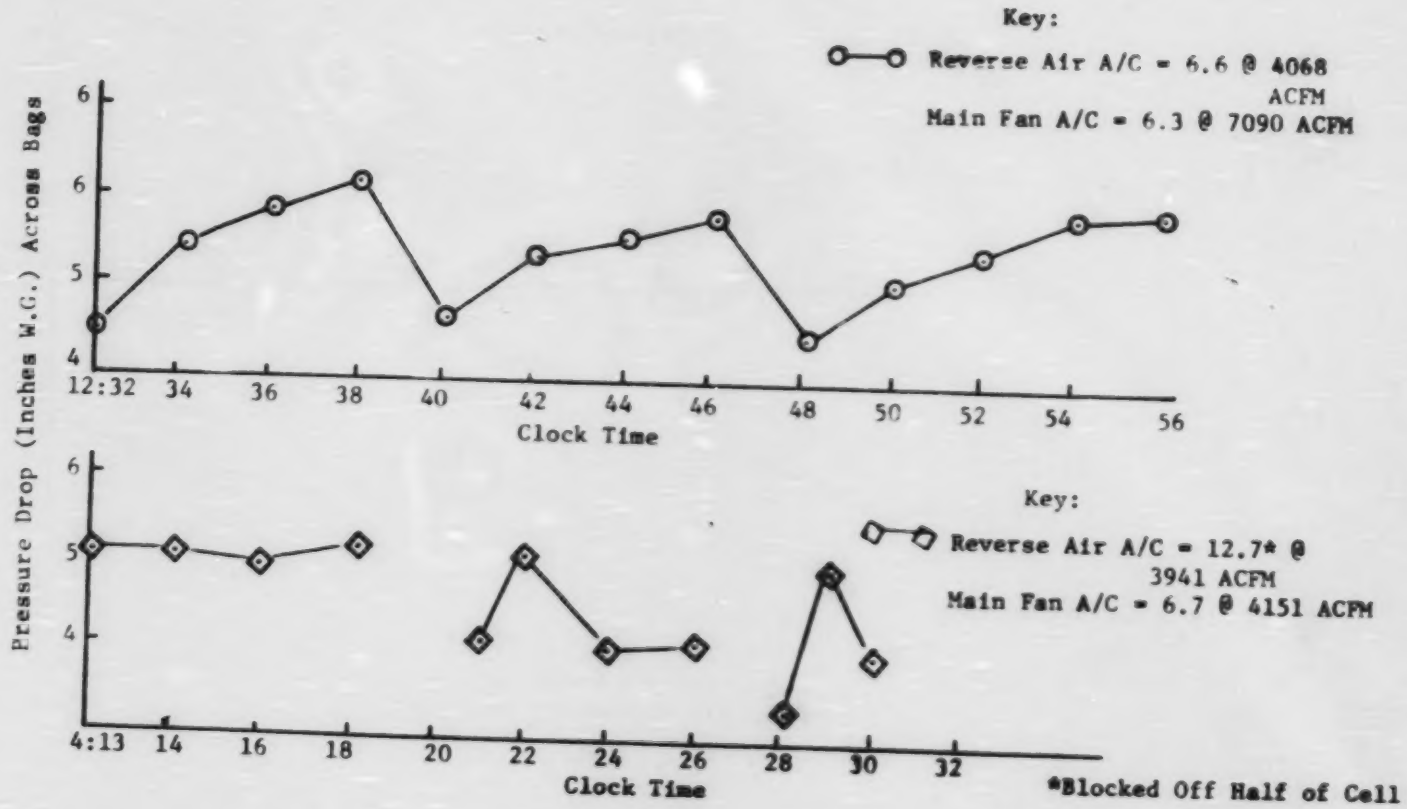


Figure 8

Variation of Reverse Air Volume
Filter Media - Nomex Felt



of reverse air. The result of this step is at the bottom of Figure 8. This last step produced a pronounced reduction in the maximum pressure drop. No attempts were made to achieve higher levels of reverse air due to physical limitations of the system. Generally, cleaning was initiated manually according to pressure drop.

Inlet particle size analysis was obtained by the use of Anderson and Pilat (University of Washington) in-situ particle size analysers. The results of these tests are shown in Figure 9. These results were obtained on a different date from those shown in Table 1. This data indicates a much finer particle size spectrum than reported by the IGCI for spreader stoker boilers.[6] A comparison is made in Figure 10. The IGCI data is based upon laboratory Bahco analyses. Outlet particle size analysis was conducted when filtering at two different gas velocities thru the filter media. These results are shown in Figures 11 and 12 and Table 1. From this data it can be seen that an increase in the filtration velocity or air-to-cloth ratio causes a significant increase in the outlet loading. Table 2 shows that even at the higher gas velocity the overall efficiency was still greater than 99.5%.

"Specific Cake Resistance" constants were determined for both Gore-Tex and Nomex. These are presented in Appendix A-2. These constants are functions not only of the cake but also the fabric and the operating conditions. The differences in the values of K_2' obtained are much greater than would be expected and indicate the need for further effort in this area.

Analysis of the inlet flue gas indicated SO_3 concentrations to be between 3.4 and 7.6 ppm while SO_2 concentrations ranged from 244 to 368 ppm.

Upon completion of the pilot plant studies a number of Nomex felt bags were removed and laboratory analysis was conducted on these bags in order to determine if any media deterioration had occurred. Table 3

Figure 9
Inlet Particle Size Distribution

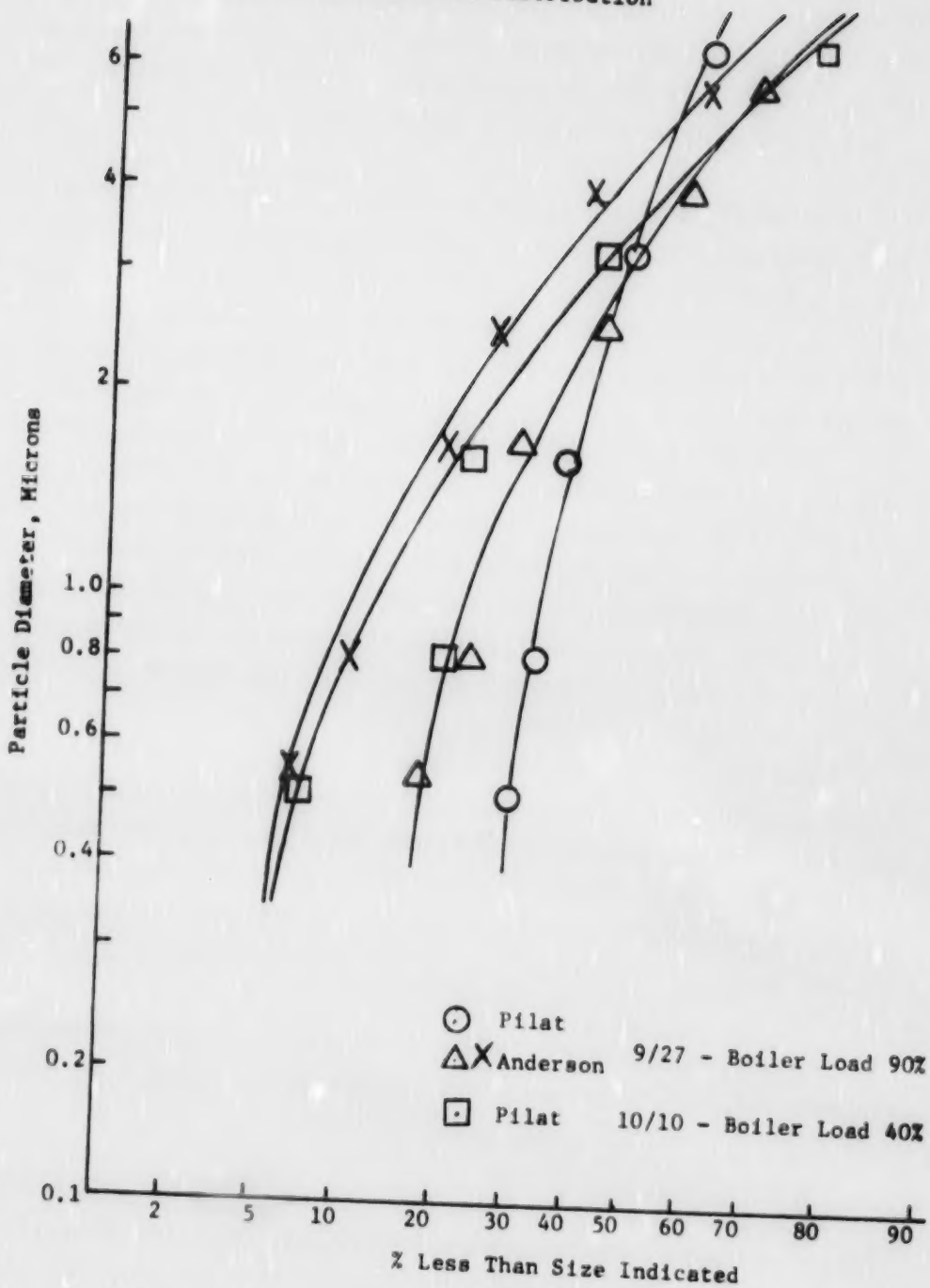


Table 1

Outlet Loadings at Different Air-to-Cloth Ratios

Filter Media - Nomex Felt

Particle Size (Microns)	High A/C ≥ 6 Outlet Load mg/scf	Low A/C ≤ 3 Outlet Load mg/scf
> 9.5	.0068	.0005
6	.0060	.0054
4	.0033	.0074
2.8	.0039	.0007
1.75	.0175	.0055
0.9	.0054	.0045
0.54	.0035	.0039
0.36	.0060	.0023
< 0.36	.0072	.0001
TOTAL	.0596	.0303

Figure 10

Comparison of Laboratory & In-Situ Particle
Size Distribution for Spreader Stoker Boilers

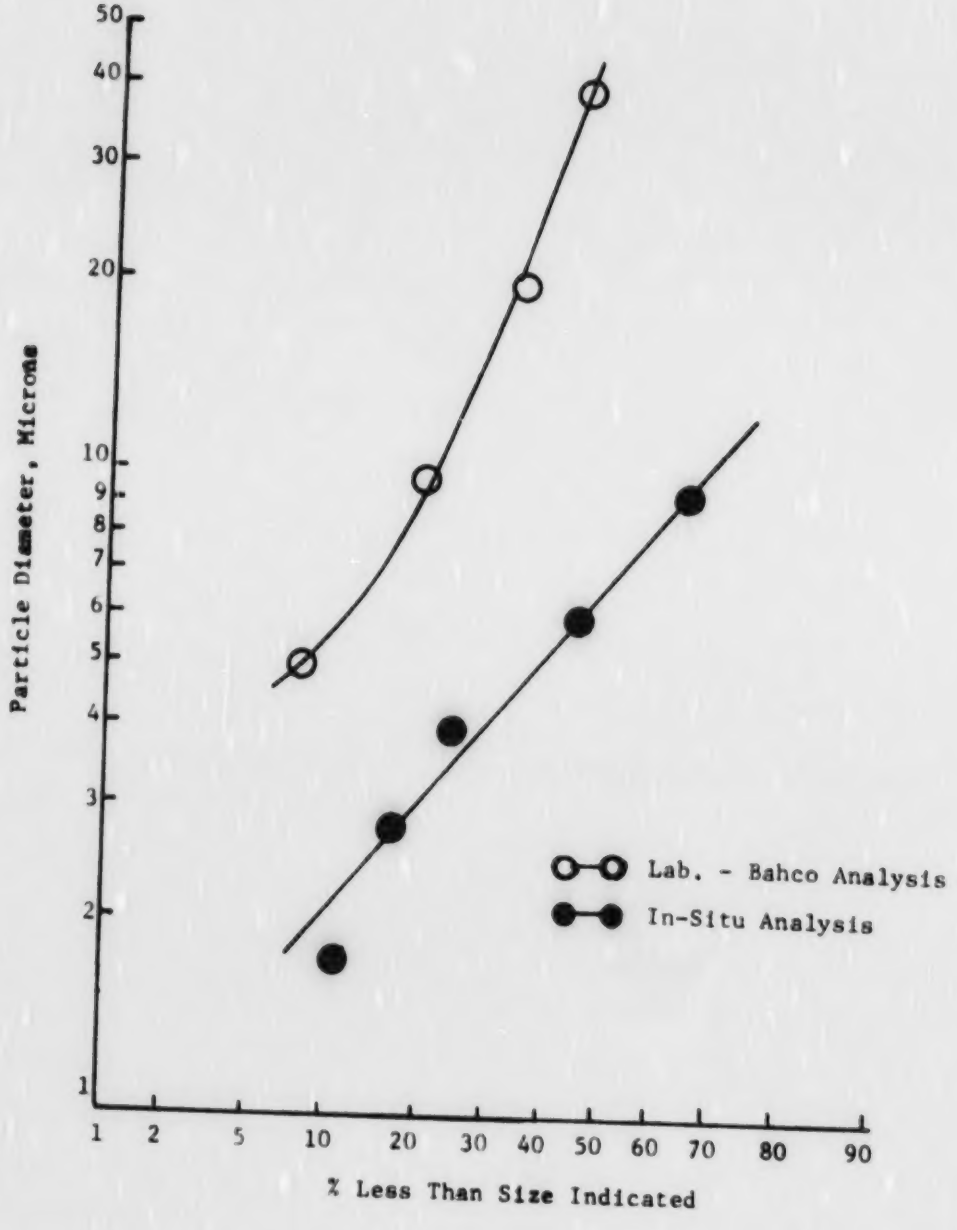


Figure 11

Outlet Particle Size Distribution
Air/Cloth @6
Nomex Felt

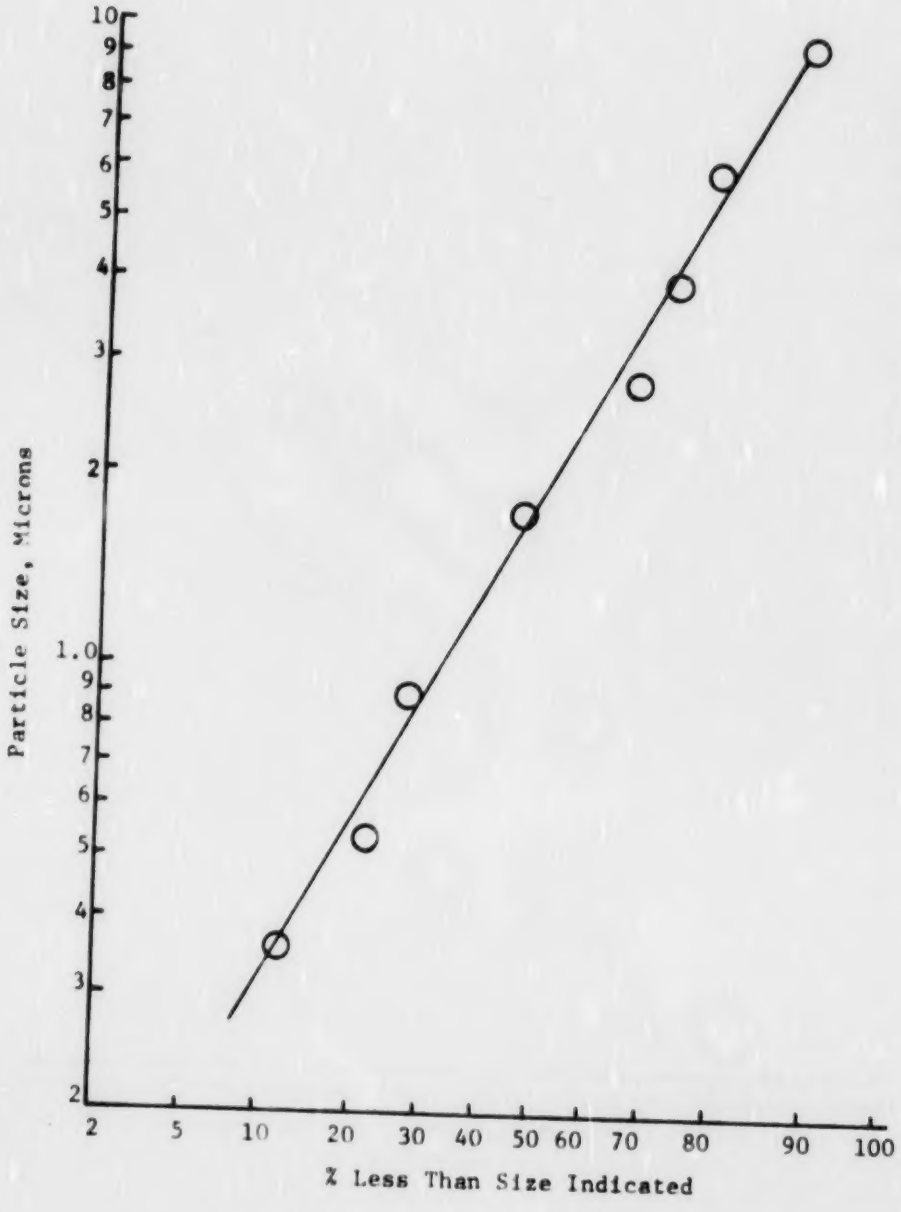


Figure 12

Outlet Particle Size Distribution
Air/Cloth ≈3
Nomex Felt

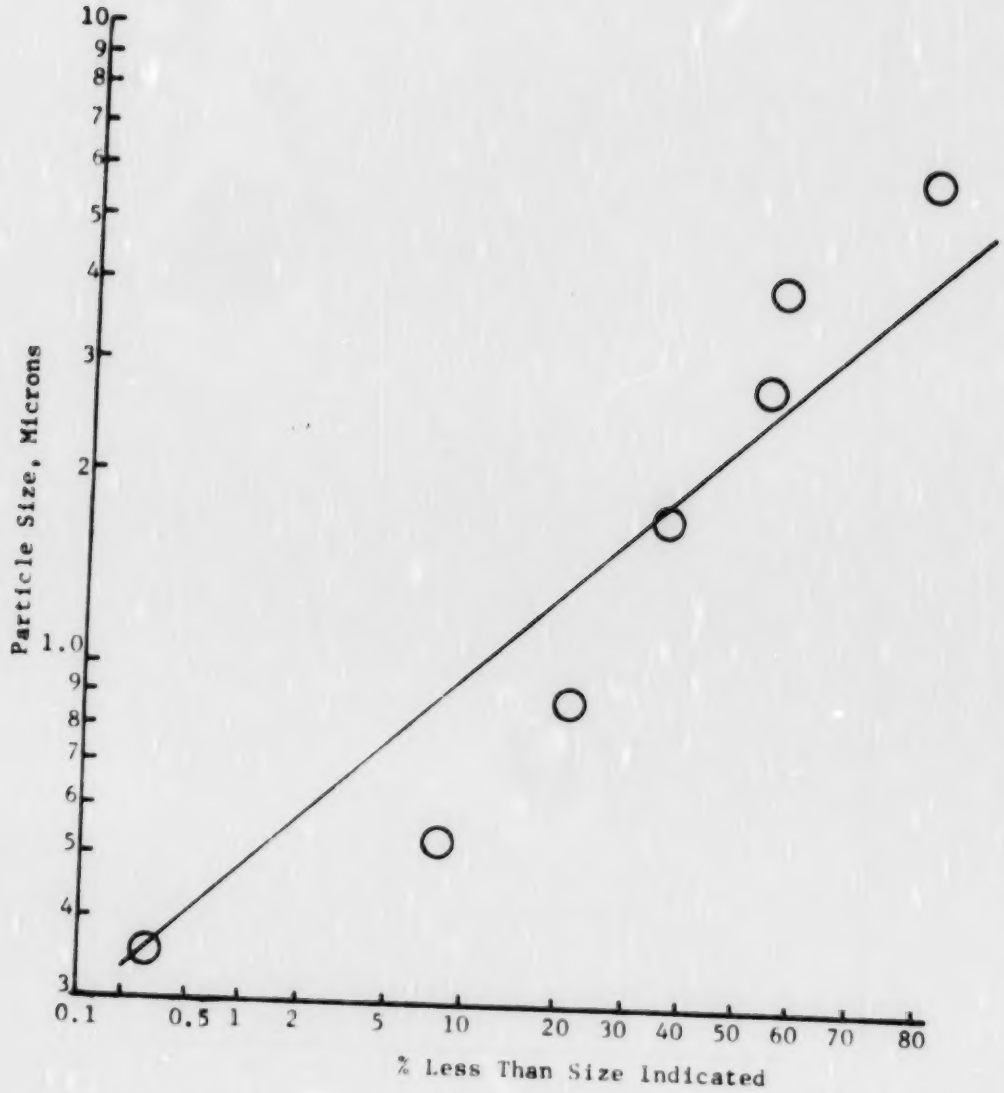


Table 2

Dust Removal Efficiencies

Filter Media Nomex Felt
Air-to-Cloth Ratio $\approx$ 6

Particle Diameter	Inlet Load mg/scf	Outlet Load mg/scf	Removal %
> 9.5	4.221	.0068	99.84
6	2.292	.0060	99.74
4	1.482	.0033	99.78
2.8	1.254	.0039	99.69
1.75	0.8893	.0175	98.03
0.9	0.6844	.0054	99.21
0.54	0.4179	.0035	99.16
0.36	0.1920	.0060	96.88
< 0.36	0.7062	.0072	98.98
TOTAL	12.140	.0596	99.51

Table 3

Data Summary of Nomex Felt Post Run Analysis

	Uncoated	Coated	
	127 Hours	13 Hours	113 Hours
Inherent Viscosity	0.95	1.61	1.13
Amine End/10^6 g polymer	7.9	0.64	3.8
Frazier Air Permeability*			
$\Delta P = 0.5"$	51	42	52
Strip Tensiles $\bar{X}$*			
B.S., lbs./in.	107	140	119
Grab Tensile, $\bar{X}$*			
B.S., lbs.	328	427	372
Wt., oz/yd.^{2}*	15.5	17.4	14.8
Thickness, mils*	121	131	124

*Permeability, Strip and Grab Tensile, Weight, and Thickness are based on ASTM tests D737, D1682-Modified, D1910 and D1777, respectively.

provides a summary of the data obtained. Inherent viscosity and amine end analysis gives an indication of chemical breakdown; i.e. the lower the viscosity and the higher the number of amine ends, the greater the fabric deterioration. The balance of the tests conducted provide primarily an indication of overall mechanical property changes. Data is given for three cases: lime coated with thirteen hours of exposure, coated with one hundred and thirteen hours of exposure and uncoated with one hundred and twenty seven hours of exposure. It is observed that both the uncoated bags and the precoated bags with over one hundred hours of exposure show significant deterioration. In addition, while the data is very limited it does appear that the precoating did slow down the degradation to some extent.

ECONOMIC CONSIDERATIONS

A preliminary evaluation of the economic factors was executed. Hardware installed costs were determined for a fabric filter dust collector sized for 70,000 ACFM at 250° F. This was done for the following fabric materials: Nomex felt, Teflon felt, Teflon woven and Gore-Tex on Nomex backing. Installed costs were also determined for a comparably sized electrostatic precipitator. All costs are based on vendor quotes obtained in February, 1974. Annual operating costs and annualized costs were then determined. Example calculations for computing costs can be found in Appendix A-5.

The installed costs for a fabric filter dust collector employing Nomex felt are provided in Figure 13. The assumptions here were firstly that it would be necessary to insulate the house and hopper and secondly that continuous lime coating of the bags is required. The air-to-cloth ratios considered were 4.3, 6.3 and 7.5. Fabric filter (baghouse) sizes versus air-to-cloth ratios are given in Table 4. The corresponding installed costs were found to be $164,000, $141,700 and $104,000 or on the basis of $ dollars per ACFM, they are $2.34, $2.02 and $1.48. These estimates were based upon a bag price of $15.50 each (vendor quote).

Similarly, installed costs were determined for the case of Teflon felt. These figures are provided in Figure 14. As in the case of Nomex, the air-to-cloth ratios considered were 4.3, 6.3 and 7.5. The corresponding installed costs were found to be $187,200, $153,300 and $115,800. On a $/ACFM basis these same costs were $2.67, $2.19 and $1.65. Because of the quick release properties of the Teflon and also its resistance to chemical attack it was assumed that no insulation and no lime coating would be required. The price of the Teflon felt bags was taken to be $50/bag (vendor quote) for the purpose of these estimates.

Figure 13

Installed Cost vs. Air-to-Cloth Ratio

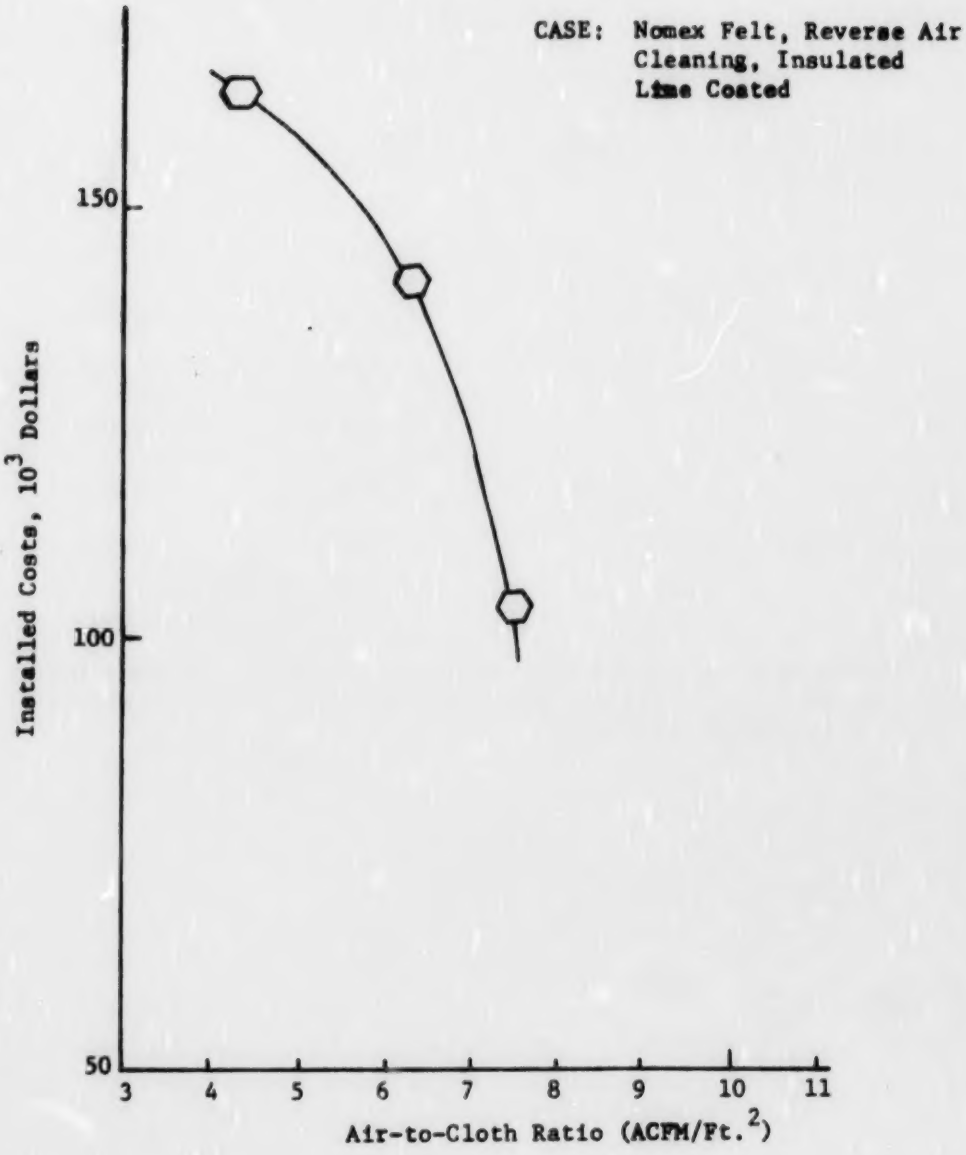


Table 4

Fabric Filter Unit Size

vs.

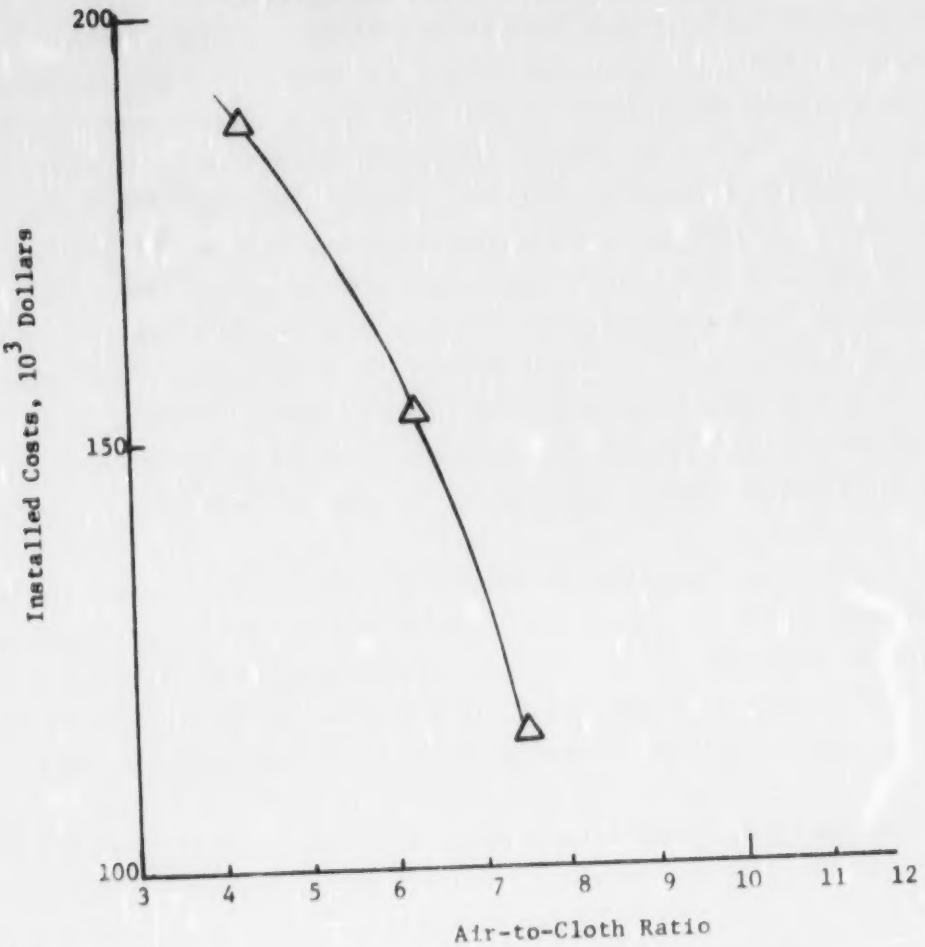
Air-to-Cloth Ratio

Air-to-Cloth Ratio	Number of Cells	Number of Bags	Net Filter Area - Sq. Ft.
2.9*	54	2,916	31,620
4.3	28	1,512	16,120
6.3	20	1,080	11,160
7.5	16	864	9,300
8.7	14	756	8,060
12.5	10	540	5,580

*Based on three (3) units: each with 18 cells, 972 bags and 10,540 ft.^{2} net filter area. One unit is always off stream due to shaker operation.

Figure 14

Installed Cost vs. Air-to-Cloth Ratio



CASE: Teflon Felt, Reverse Air Cleaning
Uninsulated, No Coating

Figure 15 provides the installed costs for the case of Gore-Tex bags. Based upon the bench studies of this material it appears that air-to-cloth ratios higher than those achievable on felt might be possible. For this reason the annualized costs were investigated up to an air-to-cloth ratio of 12.5/1. The ratios investigated were 4.3, 6.3, 7.5, 8.7 and 12.5. The corresponding annualized costs were determined to be $138,816, $118,800, $88,152, $82,948 and $72,940. On the dollar per ACFM basis these same figures are $1.98, $1.69, $1.25, $1.18 and $1.04. As with Teflon it was assumed no insulation and no coating would be required. The price of Gore-Tex is assumed to be $18 per bag (vendor quote). The inflection point in the curve of Figure 15 is due to the higher percentage of total cost attributed to the house at the lower A/C ratios as opposed to a higher percentage of total cost attributed to the bags at the higher A/C ratios.

A graphical comparison of the installed costs for these three bag materials is made in Figure 16. Teflon felt is seen to be the most expensive route for all three air-to-cloth ratios investigated and Gore-Tex is seen to be the least expensive for the same air-to-cloth ratios. The curves draw closer as the air-to-cloth ratio increases.

One case for a continuous shaker was studied. Woven Teflon bags were chosen as the filter media and an air-to-cloth ratio of 2.9 was assumed. For this case a low air-to-cloth ratio was used, simply for economic comparison. If this case is competitive then all others would be also. A bag price of $14.60 (vendor quote) was used. The capital cost was found to be about $180,000.

The installed cost for an electrostatic precipitator capable of handling 70,000 ACFM was determined for three levels of efficiency. The bases for development of these costs are provided in Table 5 These were 98, 99 and 99.5% removal efficiency. The difference in grain loading of 0.5 vs. 0.4 for Kerr boiler is not considered significant. The corresponding installed cost was determined to be $202,300,

Figure 15

Installed Cost vs. Air-to-Cloth Ratio

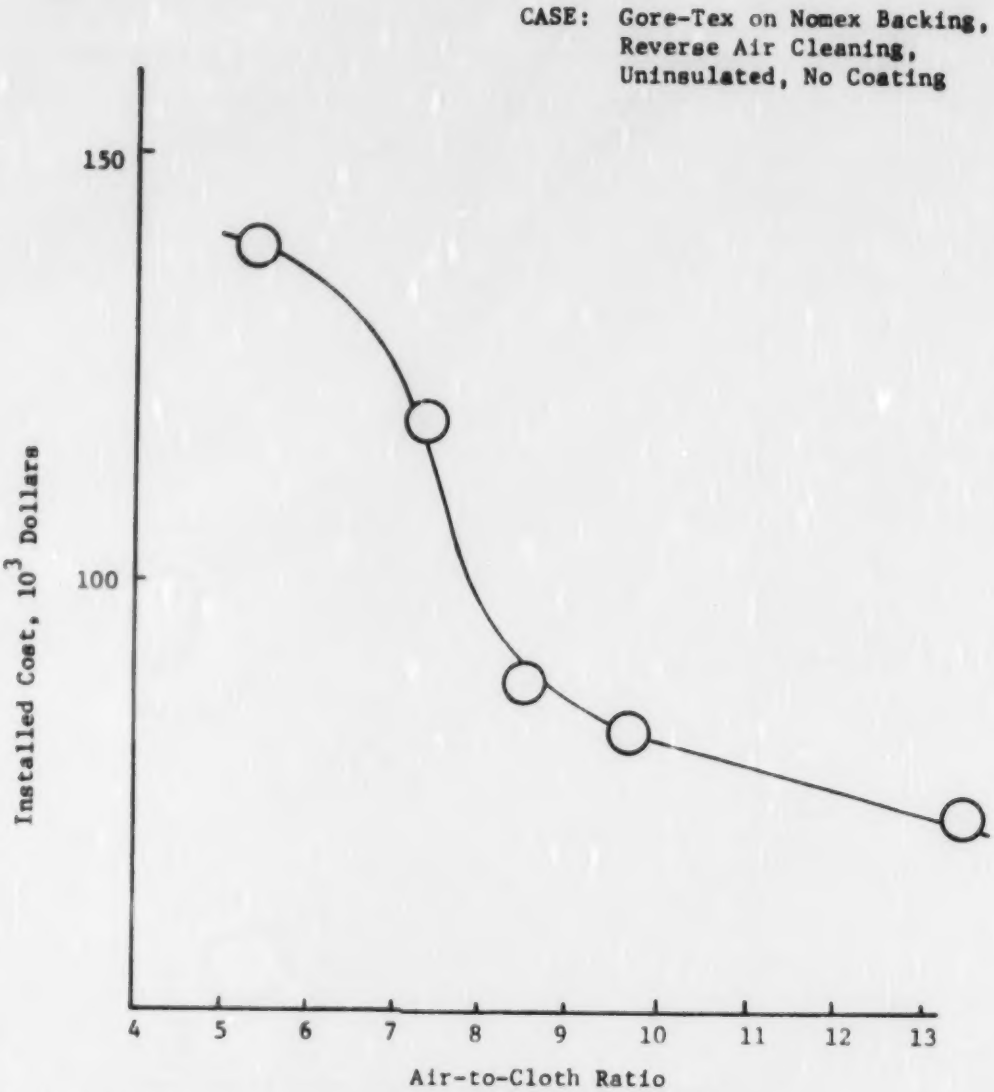


Figure 16

Installed Cost vs. Air-to-Cloth Ratio

CASES FOR EACH FABRIC SAME AS STATED INDIVIDUALLY

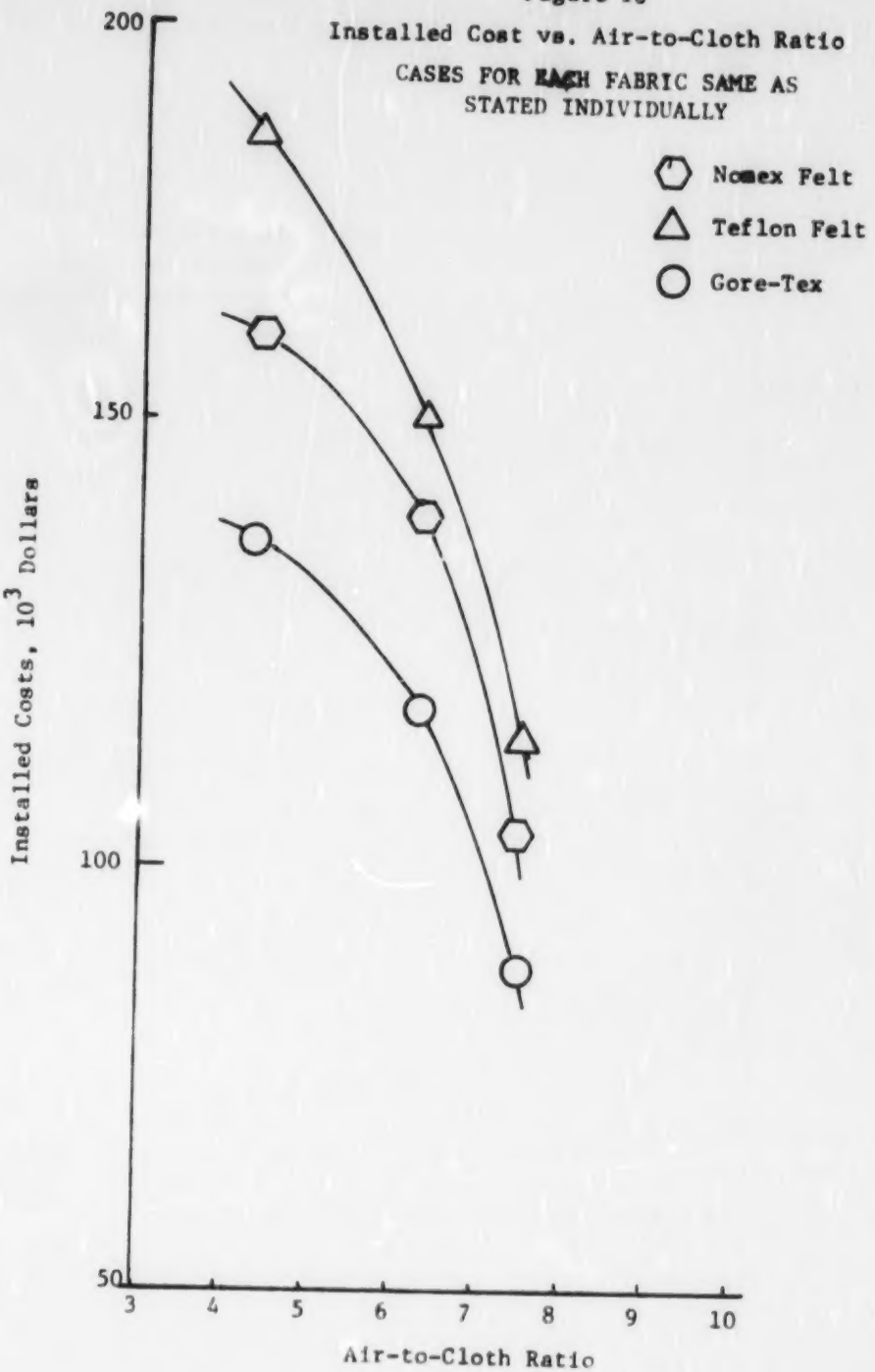


Table 5

Electrostatic Precipitator Purchase Cost Basis

Design Efficiency: 98%

Inlet Conditions: ½% S Coal, ½ Grain/ACFM Inlet Loading

Precipitator Design:

Type = Cold Precipitator

Collection Surface Requirement = 22,800 $ft.^2$

Plate Height = 30 ft.

No. of Ducts = 15

Treatment Length = 27 ft.

No. of Electrical Sections = 3 (9 ft. ea.)

No. of Power Supplies = 3 (500 milliamps each)

Assembled Flange-to-Flange Selling Price = $119,000

$248,800 and $279,200. These are shown in Figure 17. On a $/ACFM basis, these same costs are $2.89, $3.55 and $3.99. Thus the installed cost of the electrostatic precipitator even at 98% efficiency is greater than that of fabric filter dust collector even when Teflon felt is employed at an air-to-cloth ratio of 4.3.

Operating costs were also determined. For the three bag materials under study, operating costs versus air-to-cloth ratios are provided in Figure 18. The worst case of $26,200 per year was Teflon felt at an air-to-cloth ratio of 4.3; while the best base of $9,800 per year was Gore-Tex at an air-to-cloth ratio of 12.5. The main assumptions were 25% bag replacement per year and a pressure drop of 5 inches of water. Two curves for Teflon felt are given. The higher was for 25% bag replacement per year and the lower for 20% bag replacement per year.

Finally, the annualized costs were developed from the preceeding installed and operating costs. These results are shown in Figure 19 Here it is seen that at air-to-cloth ratios of 7.5 and greater all the bag materials studied will have annualized cost below that of an electrostatic precipitator operating at 98 percent efficiency.

One separate economic study conducted was aimed at evaluating the costs of preheating the inlet gas stream to the baghouse in order to determine if avoidance of dew point excursions via this route is economically feasible. Avoidance of the acid dew point is assumed to be a favorable factor in filter media life. Based upon the operating costs for various heating alternatives shown in Table 6, natural gas is the least expensive alternative. See example calculation for computing direct heating fuel costs in Appendix A-5. The capital cost for the natural gas system hardware is in the range of $2,000 to $3,000. Thus in relation to the total control system capital outlay, the heating system is a small figure; however, in terms of operating costs if a temperature rise of fifty degrees is required the annual fuel costs are still very high relative to an annual operating cost in the range of

Figure 17

Installed Costs vs. Efficiency
Case: Electrostatic Precipitator

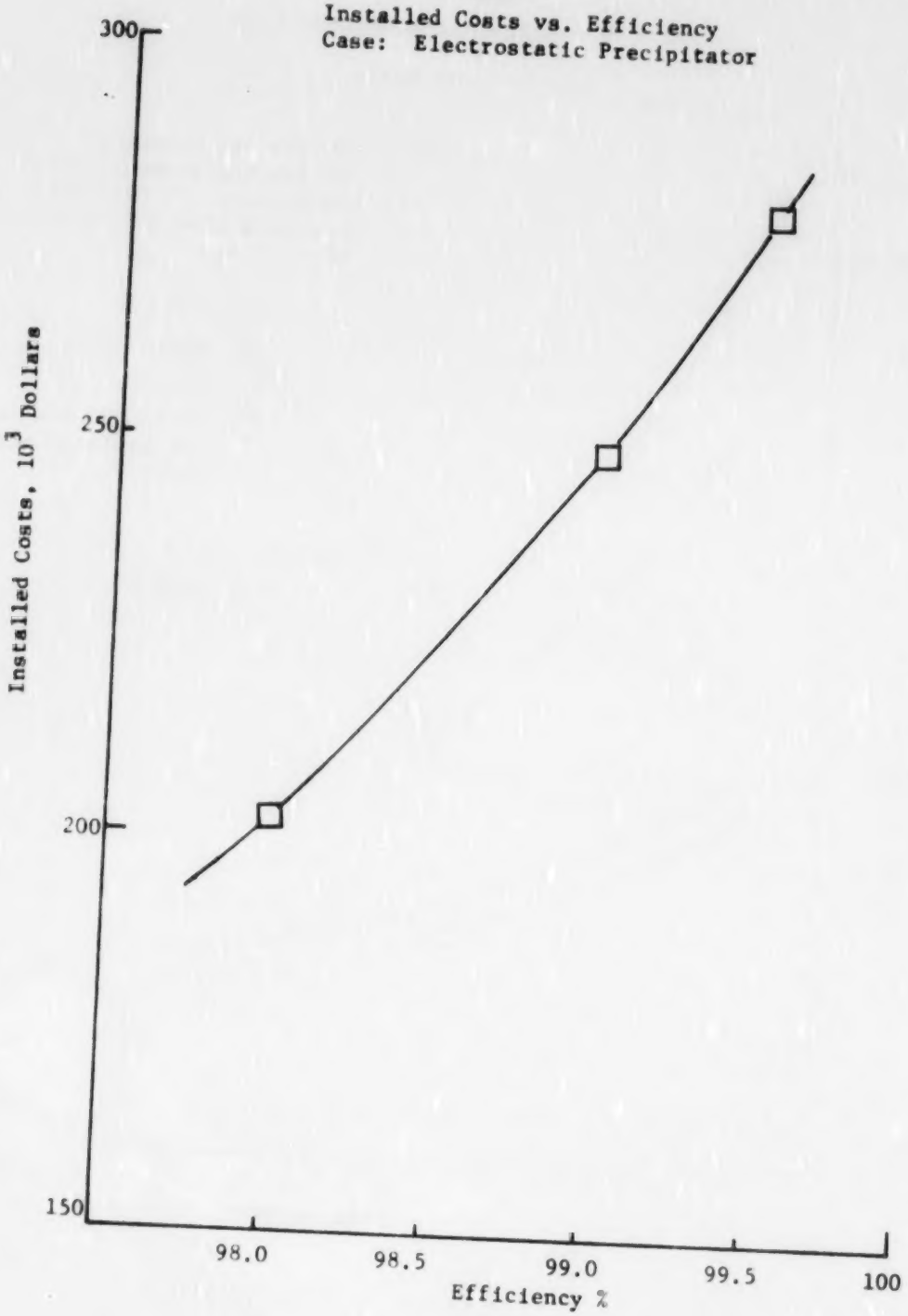


Figure 18

Annual Operating Costs
vs.
Air-to-Cloth Ratio

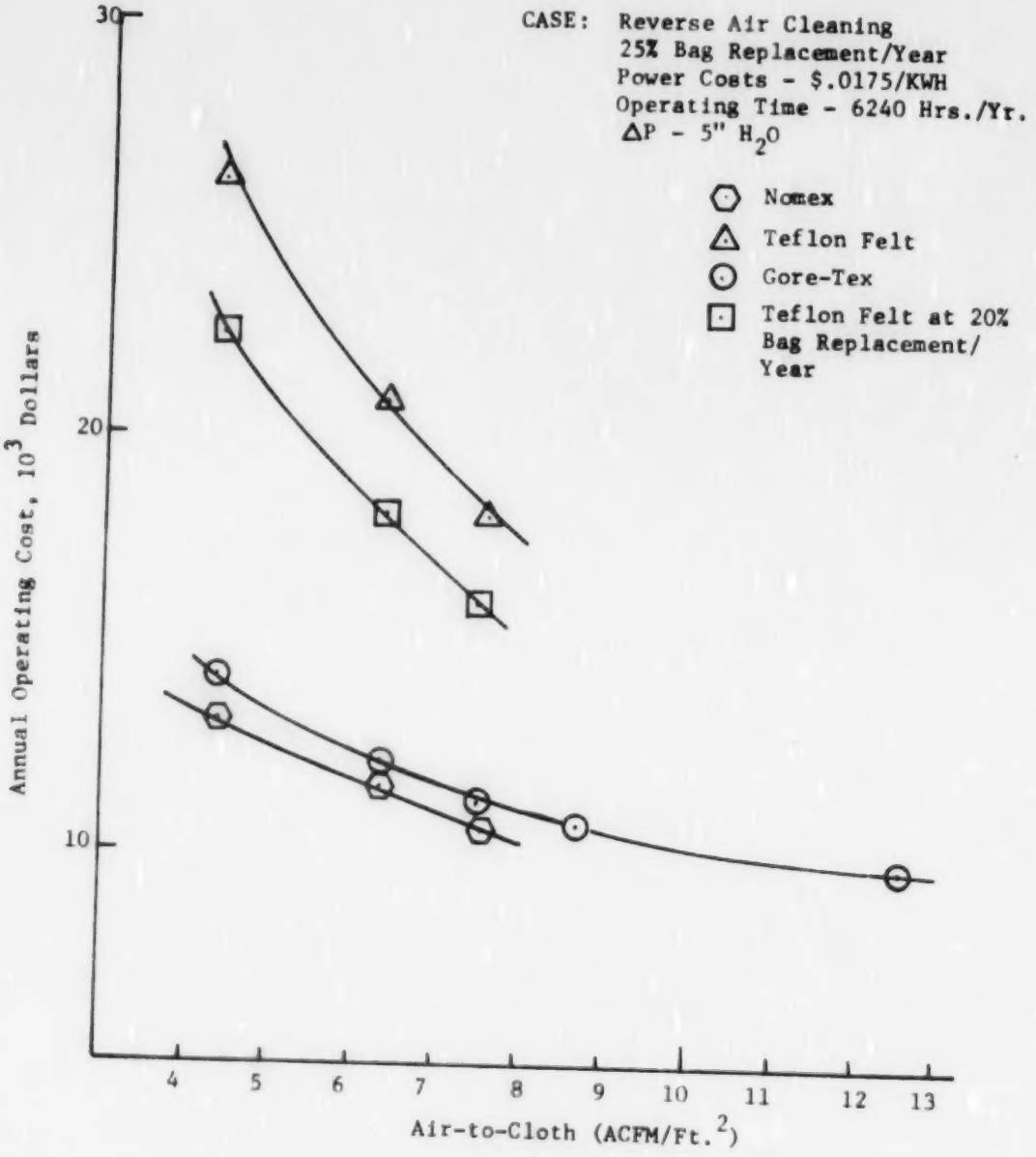


Figure 19

Annualized Cost vs. Air-to-Cloth Ratio

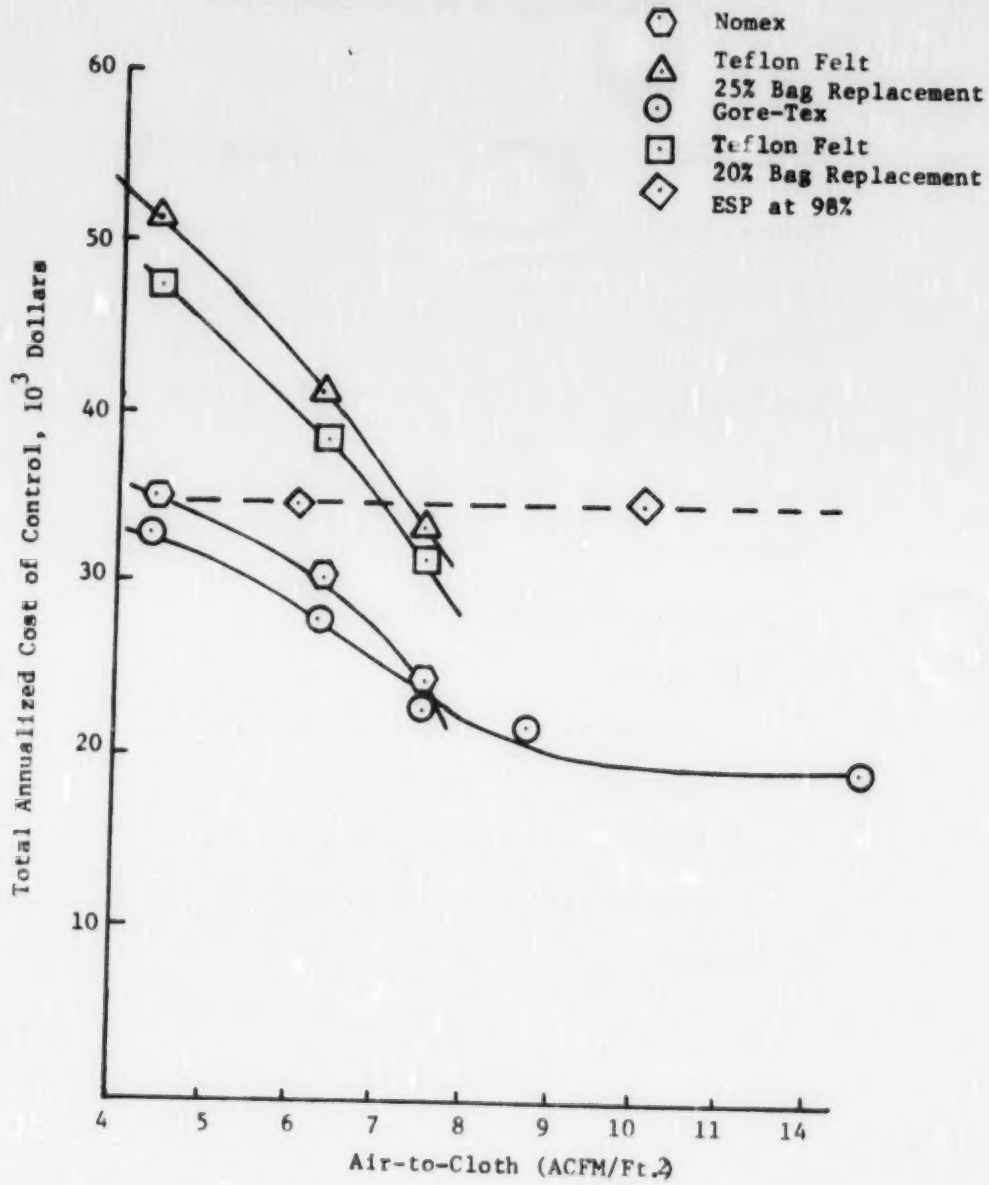


Table 6

Annual Fuel Cost

Direct Heating to Avoid Condensation

Heater Type	Dollars/Year
Natural Gas	28,500
Fuel Oil	48,200
Propane	69,200
Electricity	84,100

Assumptions:

1. Operating Hours/Year = 6,240
2. Fuel Costs:
   - Natural Gas - $1.35/Thousand Cubic Feet
   - Fuel Oil - $30¢/Gallon
   - Propane - $30¢/Gallon
   - Electricity - $.017¢/KW Hour
3. Temperature Rise 50° F

$10,000 to $14,000 as shown in Figure 18 for Nomex and Gore-Tex. It appears that direct heating is not feasible unless the dust collection system is insulated. Once insulated, it appears that the heater may not be required.

REFERENCES

1. Vandergrift, A. E., et al, "Particulate Pollutant System Study" Volume I - Mass Emissions, May 1, 1971, P.B. 203 128, see p. 50.

2. Glockley, G. H., et. al, "Dust Collectors for Low Sulfur Fossil Fuel Plants", ASME Air Pollution Control Division Proceedings April 24-25, 1973, Philadelphia, Pennsylvania.

3. Bagwell, F. A., et al, "Design and Operating Experience With a Filterhouse Installed On An Oil-Fired Boiler", Presented to Air Pollution Control Association, St. Paul, Minnesota, June 1968.

4. Borgwardt, R. H., "Filtration Characteristics of Fly Ash From A Pulverized Coal Fired Power Plant, JAPCA V18 N6, p. 387, June 1968.

5. IGCI/AMBA Joint Technical Committee Survey for Stoker Boilers.

Appendices

		Page
A-1	Filter Material Specifications and Gore-Tex Bench Results	46
A-2	K_2' Determinations	52
A-3	Annualized Cost and Direct Fired Heating Cost - Sample Calculations	55
A-4	Kerr Coal Analysis and Steam Flow Charts	59
A-5	Stack Emission Test Report	

Appendix A-1

Filter Material Specification

and

Gore-Tex Bench Results

Table A-1

Filter Media Characteristics

Filter Media	Weight Ozs./Yd.^{2}	Permeability CFM/Sq. Ft.	Mullen Burst psi	Weave Design Twill
Nomex Felt[1]	14	25-35	450	---
Teflon Felt[2] Style 2663	24-26	15-35	250	---
Gore-Tex[3]	4-5 + Laminate	8-15	329-400	---
Teflon Woven[2] Style 954	8	20-40	---	3X1
Dralon T Felt[4]	13-15	20-30	250	---

1 - High Temperature Resistant Nylon Fiber (Polyamide)

2 - Tectrafluoroethylene (TFC) Fluro-Carbon

3 - Expanded Teflon (Polytetrafluroethylene) with Interlacing Air Filled Pores

4 - Homopolymer of 100% Acrylonitrile

Table A-2

Pilot Plant Flow Data

Date & Time	Main Slide Gate Position % Open	Flow Rate (ACFM) Q_F	Q_R	Air-to-Cloth Ratio (Ft/Min) $(A/C)_F$	$(A/C)_R$	Gas Temperature t_F (°F)	t_R	Cross Cell Pressure Drop Cell #3 (In. H_2O)	Cell #4
8/16 11:24a	100	9,670	NA	7.8	NA	215	NA	4.3	4.4
8/29 3:35p	100	9,310	2,840	7.5	4.6	245	215	3.7	3.7
9/5 10:00a	100	9,340	NA	7.5	NA	235	NA	4.9	4.5
9/6 2:30p	75	8,080	NA	6.5	NA	240	NA	5.6	6.0
9/12 4:01p	100	6,240	2,700	5.0	4.4	255	200	5.6	5.1
9/13 11:19a	100	7,340	1,750	6.0	2.8	260	215	7.3	7.1
9/19 1:10p*	100	7,810	3,890	6.3	6.3	230	185	5.2	5.5
9/20 1:00p	100	7,810*	4,070	6.3	6.6	230*	170	5.7	5.8
9/20 2:15p	100	7,810*	3,730	6.3	6.0	230*	170	5.9	5.8
9/20 2:24p	100	7,810*	2,590	6.3	4.2	230*	160	5.8	5.7

Table A-2

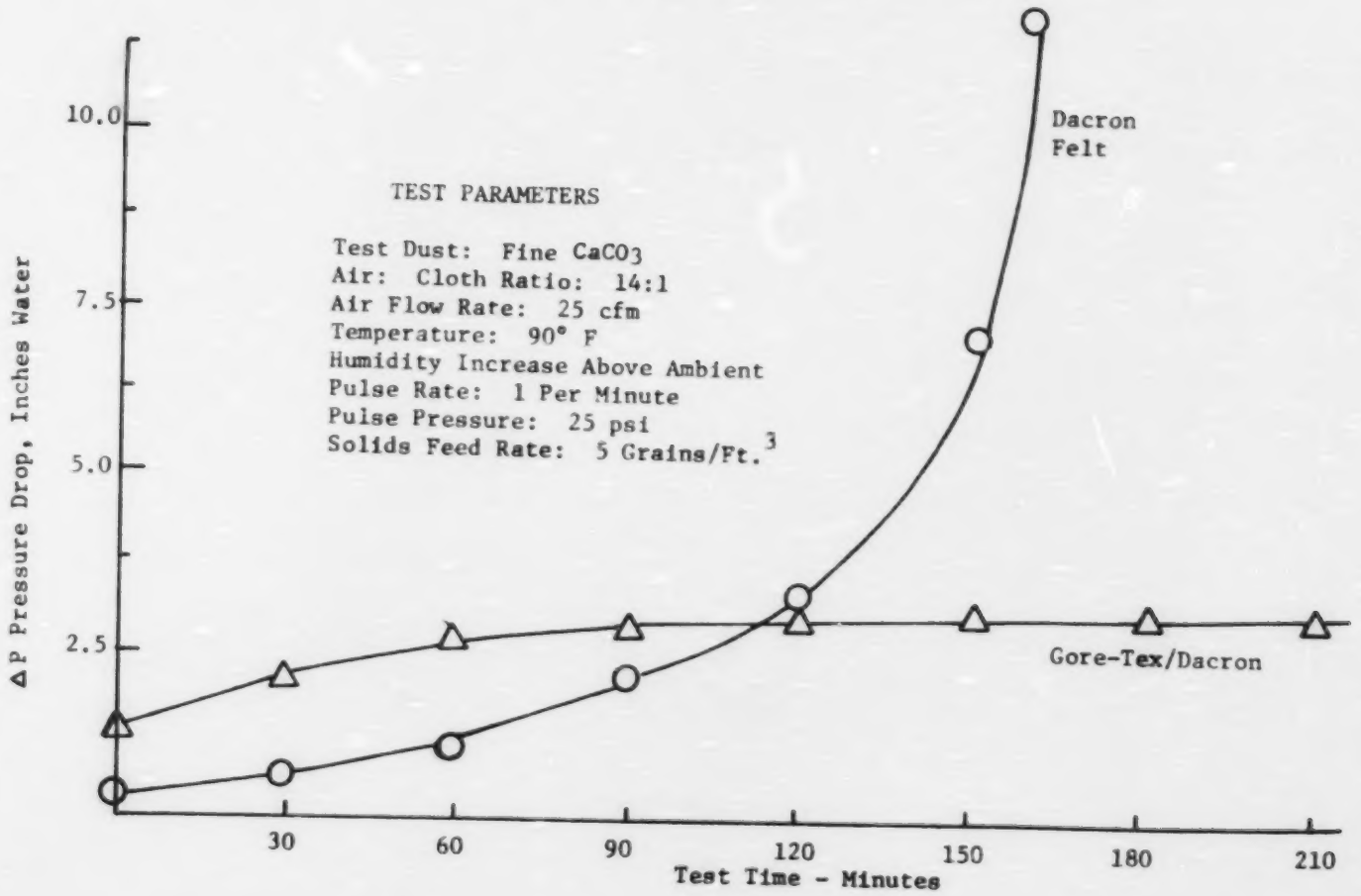
(continued)

Date & Time	Main Slide Gate Position % Open	Flow Rate (ACFM) Q_F	Q_R	Air-to-Cloth Ratio (Ft/Min) $(A/C)_F$	$(A/C)_R$	Gas Temperature t_F (°F)	t_R	Cross Cell Press Drop (In. H_2O)	
9/25 4:40p	100	4,150	3,940	6.7	12.7	230	170	4.8	4.3
9/26 12:06p	36	3,420	2,500	5.5	8.1	220	175	4.1	NA
9/26 4:50p	54	1,630	4,070	2.6	13.1	220	190	5.8	5.3
9/27 10:15a	100	9,750	3,900	15.7	12.6	222	170	5.7	5.4
9/27 12:07p	54	5,550	3,760	9.0	12.1	250	200	5.3	5.4
10/2 2:40p	54	7,050	3,420	5.7	5.5	215	180		
8/30 5:30p	100	10,600	3,440	5.7	5.6	250	230	Cell #2	Cell #3
		10,800				260		5.2	4.5
9/4	100	10,000	NA	5.4	NA	255	-	Cell #2	Cell #3
								5.4	4.6

*Q_F and Q_R not measured. Assumed equal to 9/19 values.

F = Forward Flow, R = Reverse Flow

Figure A-1
Performance of Gore-Tex Filter Bags
(Results Provided by W. L. Gore & Associates, Elkton, Md.)



Test Parameters

Air-to-Cloth Ratio: 14:1
Air Flow Rate: 25 cfm
Temperature: Ambient
Pulse Rate: 1 Pulse/Minute
Air Pressure of Pulse: 70 psi
Solids Feed Rate: 5 grains/ft.^{3}
Test Dust: Funkhauser Limestone
Data not taken on Kerr Pilot Unit

KEY:
- ○ Felted Nomex (A)
- ⬡ Felted Nomex (B)
- ◇ Felted Polyester
- □ Gore-Tex/Nomex
- △ Gore-Tex/PTFE (G-T)

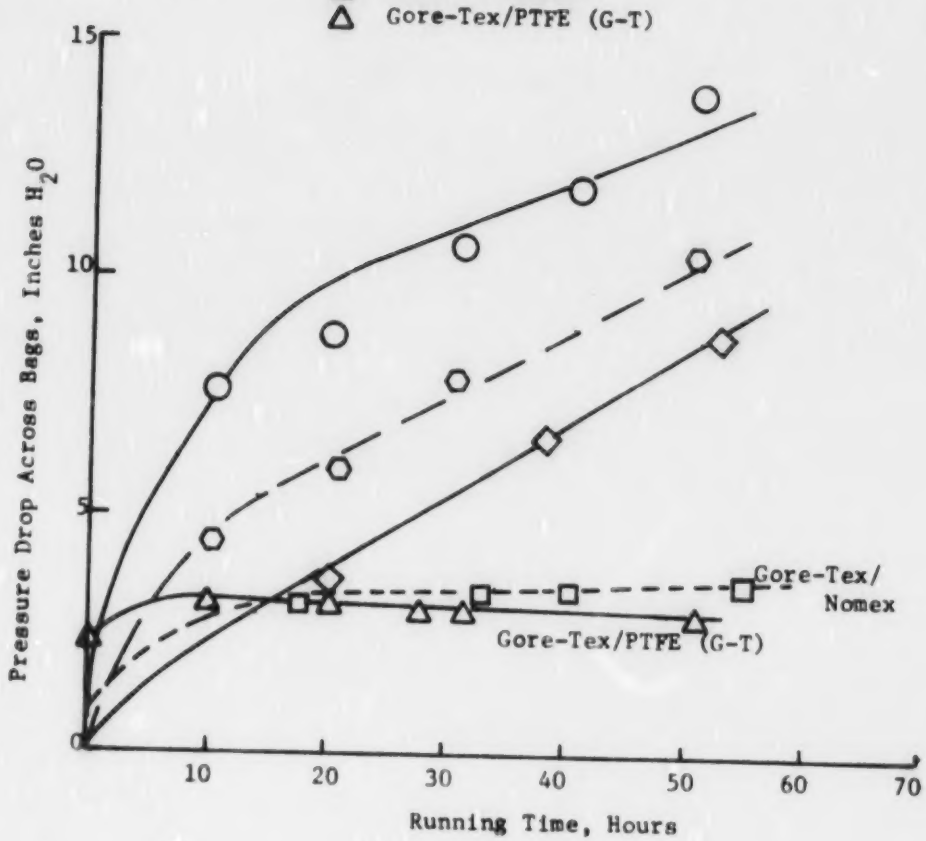


Figure A-2
Performance of Gore-Tex Filter Bags
Pressure Drop vs. Time
(Results Provided by W. L. Gore & Associates, Elkton, Md.)

Appendix A-2

K_2' Determinations

Appendix A-2

K_2' Determinations

A few determinations of the "Specific Cake Resistance" K_2' for both Gore-Tex and Nomex.

Data of 9/19/73 allowed for the following Nomex felt case calculation:

$$K_2' = \frac{(0.60)\ (620)^2\ (7000)}{7810\ (10)\ (0.8)\ (195)\ (15.43)}$$

$$K_2' = 8.6$$

Data of 8/30/73 allowed for the following Nomex felt case:

$$K_2' = \frac{(1.4)\ (620)^2\ (7000)}{5000\ (3)\ (0.8)\ (250)\ (15.43)}$$

$$K_2' = 81$$

Data of 8/30/74 allowed for the following Gore-Tex/Nomex case:

$$K_2' = \frac{(1.2)\ (620)^2\ (7000)}{5000\ (2)\ (0.8)\ (250)\ (15.43)}$$

$$K_2' = 104$$

N.B. The value chosen for the 'gas volume is based upon the assumption of equal distribution of the gas.

The above calculations were based on the following formula:

$$K_2' = \frac{(P_T - P_E)\ (A)^2\ (7000\ \text{grains/lb})}{(Q)\ (T)\ (1-F)\ (R)\ (15.43\ \text{grains/gram})}$$

Where: ΔP_T - Final pressure drop across collected dust and filter cloth, in W.C.

ΔP_E - Initial pressure drop across clean cloth, in W.C.

Formula (continued)

A = Bag area (total filtration area), $ft.^2$

T = Filtration time from start of filtration to clean down, min.

F = Fallout fraction, dust that never gets on fabric, but goes to hopper.

R = Average dust feed rate to baghouse, grams/min.

Q = Gas glow rate, ACFM

Appendix A-3

Annualized Cost and Direct Fired Heating Cost - Sample Calculations

Annualized Cost - Example Calculation

Formula for figuring theoretical annual cost (s) for operation and maintenance from Edminsten, N.G. and Bunyard, F. L., "A Systematic Procedure For Determining The Cost Of Controlling Particulate Emissions From Industrial Sources", JAPCA V20 N7, p. 446, July 1970.

$$G = S \left[\frac{0.7457}{6356E} PHK + M\right]$$

Where:

S = Design Capacity of Fabric Filter in ACFM

P = Pressure Drop, Inches of Water

E = Fan Efficiency

0.7457 = A Constant (1 hp = 0.7457 KW)

H = Annual Operating Time in Hours

K = Power Cost, Dollars Per Kilowatt-Hour

M = Maintenance Cost, Dollars Per ACFM

In this case:

S = 70,000 ACFM

P = 5 Inches of Water

E = 60%

H = 6,240 Hours

K = $.0175/KWH

M = [No. of Bags in House X 25% Replacement Rate X Cost Per Bag] ÷ S

$$M = \frac{1080 \text{ Bags} \times .25 \times \$15.50/\text{Bag}}{70{,}000 \text{ ACFM}} = \$.06/\text{ACFM}$$

Assuming a 60% fan efficiency reduces the above equation for G to

$$G = S \left[195.5 \times 10^{-6} PHK + M\right]$$

Substituting the figures above yields

$$G = 70{,}000\ [195.5 \times 10^{-6} \times 5 \times 6{,}240 \times .0175 + .06]$$

$$= 70{,}000\ [.106 + .06]$$

$$= 70{,}000\ [.166]$$

$$= \$11{,}620$$

Formula for figuring annualized capital cost is equal to depreciation plus capital charges.

Depreciation is assumed to be 6 2/3% of investment cost. The capital charges are assumed to be equal to the depreciation, therefore the annualized capital cost = .133 X total investment cost .

Total investment = \$141,660 from annualized capital =

.133 X \$141,600

= \$18,841

For the example we are working with the total annualized cost of control equals annual operating cost plus the annualized capital cost.

Total annualized cost equals \$18,841 + \$11,620 = \$30,461

Direct Heating Fuel Cost - Example Calculation

1. BTU/Hr. = (SCFM Air) (1.1) (ΔT°F)

$$70{,}000 \times \frac{460 + 32}{460 + 240} = 70{,}000 \times \frac{492}{700} = 49{,}200 \text{ SCFM}$$

$$\text{BTU/Hr.} = (49{,}200)\ (1.1)\ (50)$$

$$= 2.706 \times 10^6 \text{ BTJ/Hr.}$$

$$2.706 \times 10^6 \text{ BTU/Hr.} \times 6{,}240 \text{ Hr.} = 1.69 \times 10^{10} \text{ BTU}$$

2. Fuel oil is rated at 140,000 BTU/Gal. At .75% efficiency oil puts out 105,000 BTU/Gal. Oil costs $.30/Gal.

$$\frac{2.706 \times 10^6 \text{ BTU/Hr.}}{.105 \times 10^6 \text{ BTU/Gal.}} = 25.77 \text{ Gal. Hr.}$$

$$25.77 \text{ Gal.Hr.} \times \$.30/\text{Gal.} \times 6{,}240 \text{ Hrs.} = \$48{,}200$$

Appendix A-4

Kerr Coal Analysis

and

Steam Flow Charts

GENERAL TESTING & ENGINEERING COMPANY
Whitewood, Virginia

COMPANY: Jno. McCall Coal Company, Inc.

ADDRESS: Bluefield, West Virginia

MINE NAME: Loftis #2

LOCATION: Sharondale, Kentucky

SEAM: Cedar Grove

SIZE OF COAL: 1-1/4 X 1/4"

IDENTIFICATION: N&W 20376

DATE SAMPLED: 12/20/72

SAMPLED BY: G. Scott

SAMPLE RECEIVED: 12/21/72

SAMPLE SUBMITTED: 12/22/72

CERTIFICATE OF ANALYSIS

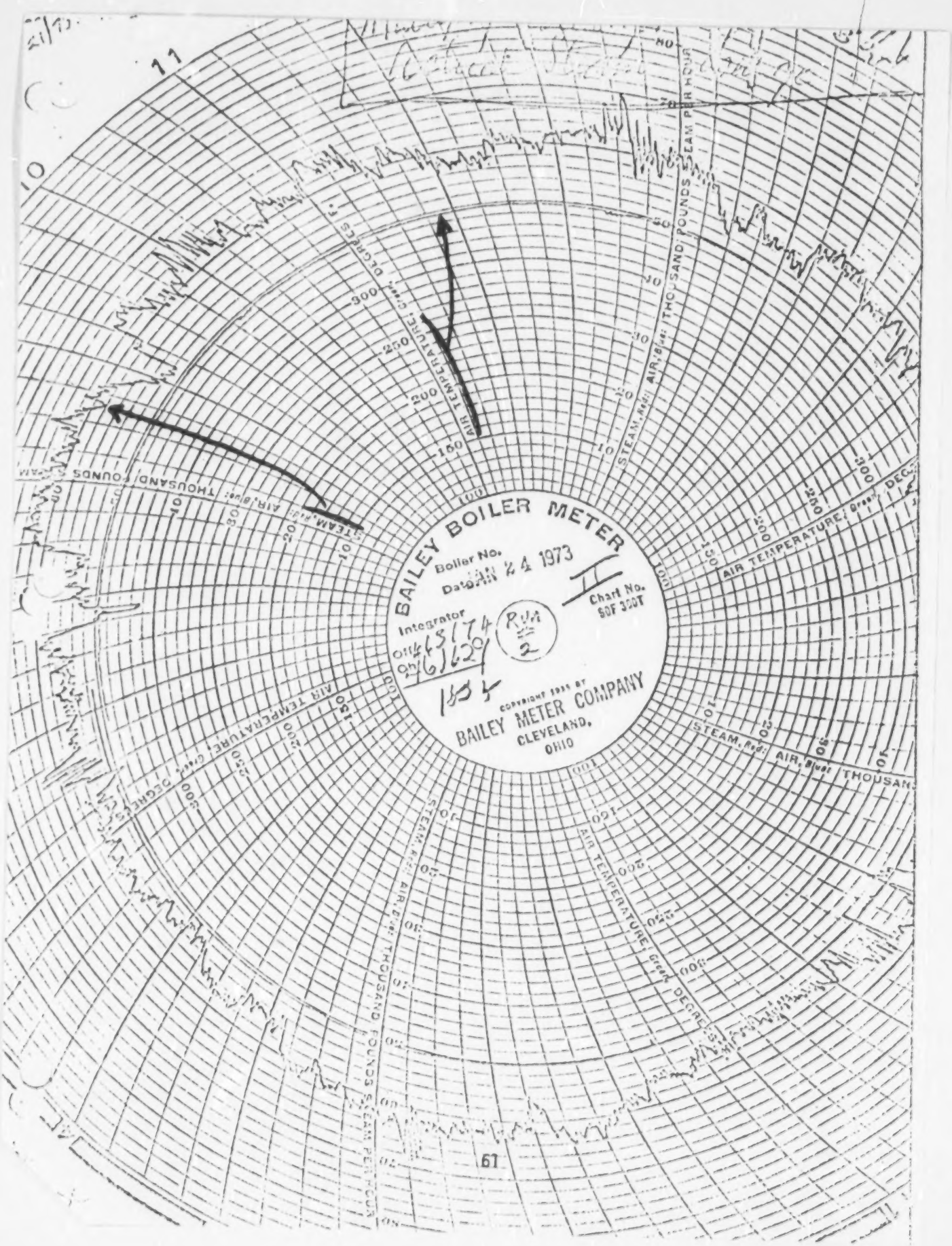
Laboratory Number

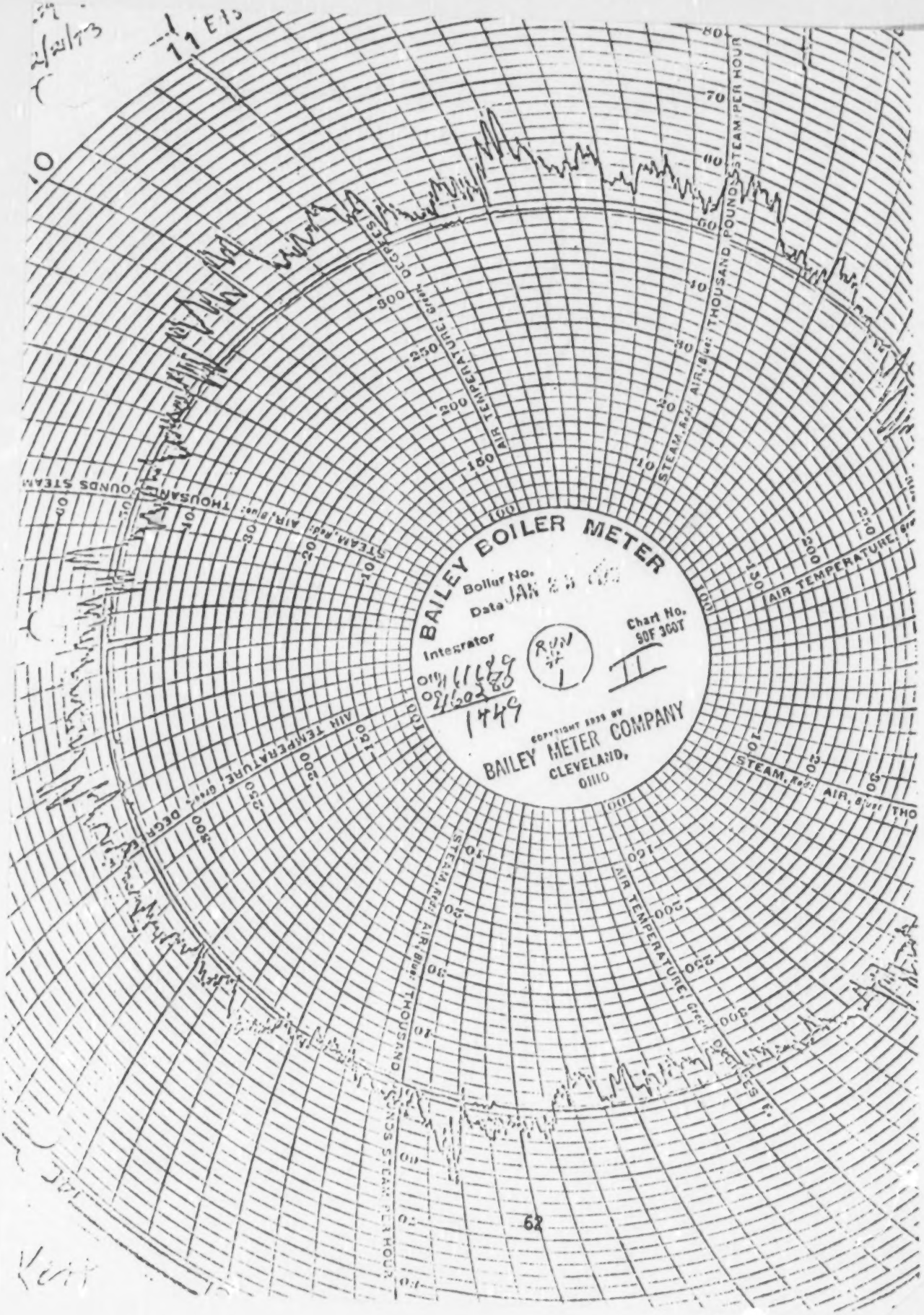
	As Received	Dry
% Moisture	4.00	
% Volatile Matter	35.00	36.45
% Fixed Carbon	54.85	57.14
% Ash	6.15	6.41
Total	100.00	100.00
% Sulphur	.60	.62
BTU	13,850	14,427

Fusion Temperature of Ash 2800 Plus

Free Swelling Index

Hardgrove Grindability Index


BAILEY BOILER METER
Boiler No.
Date JAN 24 1973
Chart No. 50F 350T
Integrator
Off 45174
On 46120
RUN 2
154
COPYRIGHT 1955 BY
BAILEY METER COMPANY
CLEVELAND, OHIO
AIR TEMPERATURE
STEAM, AIR, THOUSAND POUNDS STEAM PER HOUR
AIR TEMPERATURE DEGREES
STEAM, AIR, THOUSAND POUNDS STEAM PER HOUR


BAILEY BOILER METER
Boiler No.
Date JAN 23
Integrator
Chart No. SOF 3COT
RUN
1
1749
COPYRIGHT 1955 BY
BAILEY METER COMPANY
CLEVELAND, OHIO
STEAM, Pounds per Hour
AIR TEMPERATURE, Degrees F
STEAM, Pounds per Hour
AIR TEMPERATURE, Degrees F

Appendix A-5

Stack Emission Test Report

INTRODUCTION

This report was prepared for the purpose of presenting the results of emission tests conducted on January 23 and 24, 1973 at Kerr Industries, Inc., Concord, North Carolina. The tests were performed on one of two coal-fired boilers and were conducted by Michael Y. Aldridge of the North Carolina Office of Water and Air Resources, Air Quality Division, and R. W. Buck of L. E. Wooten and Company.

CONTENTS

Introduction	Page 1
Description of Boiler	Page 2
Sampling and Analytical Procedure	Page 2
Presentation and Discussion of Results	Page 3
Calculation Procedures	Appendix A
Analytical Data and Test Data	Appendix B
Stack Gas Analysis	Appendix C
Field Data	Appendix D
Steam Flow Charts	Appendix E

A BRIEF DESCRIPTION OF BOILER ON WHICH TESTS WERE PERFORMED

The steam generating facilities at Kerr Industries consist of two Babcock and Wilcox boilers which are equipped with "Detroit Rotostoker" spreader stokers. These boilers have a design capacity of sixty thousand pounds of steam per hour, each with a two-hour peaking capacity of seventy thousand pounds per hour. The design efficiency of these units is 82 percent. Based on the above parameters, the heat input for these units is 73.2 million BTU/hr each. Both boilers are equipped with fans for supplying draft and unit number two has overfire steam injection for better combustion control.

SAMPLING AND ANALYTICAL PROCEDURES

Equipment

The sampling train used for the tests described herein was the E. P. A. type particulate train described in the Federal Register dated December 23, 1971, Volume 36, Number 247, Part II.

Sampling Schedule

Boiler number two was selected for testing and Kerr Industries assumed the responsibility of installing ports in the stack. The ports were situated 90° apart from each other. The equipment set up was completed on January 22. One two-hour run was made on each of the following days; each run consisted of spending ten minutes at each of twelve sampling points. The filter holder was not large enough to handle the encountered concentrations, making it necessary to stop periodically during testing to change filters. Run #1 required the use of four filters; run #2 required the use of three filters. Each filter was placed in a separate, labeled container.

Sample Clean Up

At the end of each test run, the volumes of water condensed in the impingers were measured to the nearest 1.0 ml. The silica gel from the fourth impinger was transferred to a collecting jar and sealed. The last filter was carefully removed from its holder and placed in a container and sealed. The probe, cyclone, and the inlet side of the filter holder were washed with acetone. The washings were captured in a collecting jar and sealed.

Analysis

The probe and cyclone washings were transferred to pre-weighed beakers and placed in an oven at 90° C. The acetone was evaporated, after which, the beakers were removed from the oven and allowed to assume room temperature. The beakers, with the residues they contained, were then weighed on an analytical balance to the nearest 0.1 milligram. The tare weights of the beakers were subtracted to determine the weight of the particulate residue. The filters were similarly weighed and their tare weights subtracted. The total particulate weight for a given run was considered to be the sum of the beaker residues from the washings and the weight differential of the filter.

The silica gel was weighed to the nearest 0.1 gram. The dry weight of the silica gel was subtracted to obtain the weight of water captured. This quantity, expressed on a volume basis, was added to the volume of water condensed in the first three impingers. This sum was considered to be the total volume of water captured.

PRESENTATION AND DISCUSSION OF RESULTS

The results of the first run indicate a particulate emission rate of 131.4 lb/hr. The results of the second run indicate an emission rate of 135.6 lb/hr.

The particulate regulation which relates to emissions from coal-fired boilers is stated as follows:

"No person shall cause, suffer, allow or permit particulate matter caused by the combustion of a fuel to be discharge from any stack or chimney into the atmosphere in excess of the hourly rate set forth in the following table:

Heat Input in Million BTU/hr	Maximum Allowable Emission of Particulate Matter in Lbs/million BTU
Up to and including 10	0.60
100	0.33
1000	0.18
10,000	0.10"

In order to determine the allowable emission rate, the heat input capacity of the unit must be determined. This determination is made on the basis of design parameter as follows:

Design Steam Rate	60,000 lb/hr
Design Efficiency	82%
BTU Input	73.2 million BTU/hr (Based on 1000 BTU/lb. steam)

A graph in the back of the "North Carolina Rules and Regulations Governing the Control of Air Pollution" and referred to therein as Figure 1 gives emission rates for all heat input. This graph eliminates the need for interpolating the table which accompanies the regulation.

The emission factor (corresponding to a 73.2 million BTU/hr. input) taken from this graph is 0.36 lb/million BTU.

The application of this emission factor is based on the actual operation conditions which existed during the test runs. These conditions are as follows:

	Run #1	Run #2
Actual Steam Rate, 1000 lb/hr (average from disk chart)	53.7	59.5
Operating Efficiency (supplied by Kerr Industries)	77%	77%
BTU Input (million BTU) (Based on 1000 BTU/lb. steam)	69.7	77.3

	Run #1	Run #2
Maximum Allowable Emission Rate - lb/hr.	25.1	27.8
Actual Emission Rate - lb/hr.	131.4	135.6

The above table shows that the boiler tested at the site of Kerr Industries, Inc., Concord, North Carolina is (according to the results of those tests) in violation of the applicable standard.

This report completed by:

Michael Y. Aldridge

Michael Y. Aldridge
Engineer
North Carolina
Air Quality Division

MYA:bjm

Appendix A

CALCULATION PROCEDURES

The following are the formulae used in calculating the results for each test run.

1. Stack Velocity:

$$V_s = K_p C_p \sqrt{\frac{T_s}{P_s M}} \sqrt{\Delta p}$$

Where:

V_s = Average stack velocity, ft/sec

K_p = Units conversion factor = 85.48

C_p = Pitot tube coefficient = .85

T_s = Stack temperature, °R

P_s = Absolute stack pressure, in. Hg

M = Molecular wt. of gas, lb./lb. mole

Δp = Velocity pressure, in. H_2O

2. Stack Volume Flow Rate:

$$Q = 60 v_s A_s$$

Where:

Q = Stack volume flow rate, $ft.^3/min.$

v_s = Stack velocity, ft./sec.

A_s = Cross sectional area of stack, $ft.^2$

3. Sample volume corrected to stack conditions:

$$V_{m_s} = V_m \frac{T_s}{T_m} \frac{P_m}{P_s}$$

Where:

V_{m_s} = Sample volume corrected to stack conditions, $ft.^3$

V_m = Sample volume as measured by dry gas meter, $ft.^3$

T_s = Absolute stack temperature, °R

T_m = Average absolute temperature of dry gas meter, °R

P_m = Absolute pressure of dry gas meter, in.Hg

P_s = Absolute pressure in stack in. Hg

4. Volume of water vapor collected, corrected to stack conditions:

$$V_v = .00267\ V_{Lq}\ \frac{T_s}{P_s}$$

Where:

V_v = Vapor volume, $ft.^3$

V_{Lq} = Liquid volume, ml.

T_s = Absolute stack temperature, °R

P_s = Absolute stack pressure, in. Hg

5. Total sample volume at stack conditions:

$$V_{sample} = V_{m_s} + V_v$$

Where:

V_{sample} = Total wet volume of gas drawn into sampling train, $ft.^3$

V_{m_s} = Dry sample volume, $ft.^3$

V_v = Vapor volume, $ft.^3$

6. Pollutant mass rate based on particulate concentration:

$$PMR_c = (0.1323) \frac{W_t \quad Q}{V_{sample}}$$

Where:

PMR_c = Pollutant mass rate (concentration method), lb./hr.

W_t = Total weight of particulate matter collected for a given run, gm.

Q = Stack volume flow rate, $ft.^3/min.$

V_{sample} = Total sample volume, $ft.^3$

7. Pollutant mass rate calculated on the basis of the ratio of the cross sectional areas of the stack and the sampling nozzle:

$$PMR_a = (0.1323) \frac{W_t \quad A_s}{\theta \quad A_n}$$

Where:

PMR_a = Pollutant mass (ratio of areas method) lb./hr.

W_t = Total weight of particulate matter collected for a given run, gm.

A_s = Cross sectional area of stack, $in.^2$

θ = Duration of test run, min.

A_n = Cross sectional area of sampling nozzle, $in.^2$

8. Percent isokineticity, % I:

$$\%I = (100) \frac{PMR_a}{PMR_c}$$

9. Average pollutant mass rate, PMR_{ave}:

$$PMR_{ave} = \frac{PMR_a + PMR_c}{2}$$

Appendix B

ANALYTICAL DATA AND TEST DATA

ANALYTICAL DATA

Run #	1	2
Filter weight differential, gm.	0.4709	0.4009
Residue from probe washings, gm.	3.1139	3.2600
Total particulate weight, gm.	3.5848	3.6609
Impinger water, volume differential, ml.	89	97
Silica gel weight differential, gm.	12.7	14.5
Total water volume, ml.	101.7	111.5

Appendix C

STACK GAS ANALYSIS

An Orsat analysis was made on the stack gas in order to determin its molecular weight.

The results are as follows:

Constituent	Qy., ml.				Molecular Weight		
CO_2	9.5	x	10^{-2}	x	44	=	4.18
O_2	10.0	x	10^{-2}	x	32	=	3.20
CO	0.0	x	10^{-2}	x	28	=	0.00
N_2	80.5	x	10^{-2}	x	28	=	22.54
Average Molecular Weight	=						29.92 lb/lb mole.

TEST DATA

Refer to Appendix A for Nomenclature

Run #	1	2
V_s, ft./sec.	49.16	48.28
Q, c. f. m.	35,925	35,285
V_m, ft.^{3}	87.6	82.3
V_{m_s}, ft.^{3}	132.5	126.1
P_m, in. Hg	29.30	29.40
P_s, in. Hg	29.25	29.35
V_v, ft.^{3}	7.59	8.26
V_{sample}, ft.^{3}	140.1	134.4
PMR_c, lb./hr.	121.6	127.2
PMR_a, lb./hr.	141.2	144.2
%I	116.1	113.4

Appendix D

FIELD DATA

AIR QUALITY DIVISION

SOURCE SAMPLING FIELD DATA

Plant Kerr Industries
Date January 23, 1973
Location Concord, N. C.
Sample Type Particulate
Run Number 1
Operator M. Y. Aldridge
Sample Box No. 1
Meter Box No. 1

Meter $\Delta H_@$ 2.37
C Factor 1.4
Probe Type Stainless Steel
Probe Length 5 ft.
Probe Tip Dia., In. 0.25
Probe Heater Setting 25%
Heater Box Setting 250
Assumed Moisture % 5%

Ambient Temperature 70°F
Barometric Pressure, In. Hg. 29.30
Static Pressure (P_s), -0.62 in. H_2O
Stack Dimension(s) 47.25 in Diameter
Distance: Disturbance to port 32ft.
Distance: Port to exit 35ft.
Reference Δp .55
Filter number(s) 119, 120

Remarks:

TRAVERSE POINT NUMBER	CLOCK TIME (24 hr CLOCK) / SAMPLING TIME, min (11:00 A.M.)	GAS METER READING (V_m), ft^3	VELOCITY HEAD (Δp_s), in. H_2O	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O		STACK TEMPERATURE (T_s), °F	DRY GAS METER TEMPERATURE		PUMP VACUUM, in. Hg	SAMPLE BOX TEMPERATURE, °F	IMPINGER TEMPERATURE, °F
				DESIRED	ACTUAL		INLET ($T_{m\,in}$), °F	OUTLET ($T_{m\,out}$), °F			
E 1	00	246.30	.32		.62	360	72	69	1.0	250	60
1	05	249.02	.32		.62	360	74	69	1.5	250	56
2	10	251.68	.40	.95	1.5	360	78	70	6.5	250	56
2	15	255.65	.40	.95	1.5	360	81	71	8.5	250	57
3	20	259.57	.45	1.0	.95	360	84	74	8.0	250	57
3	25	262.90	.45	1.0	.95	360	85	75	8.5	250	56
3	30	266.30	.46		1.0	360	85	76	9.0	250	57
CHANGE FILTER											
E 4	30	266.30	.55		1.3	355	76	73	2.5	250	56
4	35	270.20	.56		1.3	357	79	73	5.0	250	54
5	40	273.76	.60		1.4	355	82	74	6.5	250	56
5	45	277.73	.60		1.4	355	84	75	8.0	250	56
6	50	281.77	.60		1.4	355	86	77	9.0	250	57
6	55	285.77	.60		1.4	355	86	77	10.0	250	59
6	60	289.37	.60		1.4	355	88	78	12.0	250	61
	12:30 P.M.										

AIR QUALITY DIVISION

SOURCE SAMPLING FIELD DATA

Plant Kerr Industries

Date January 23, 1973

Location Concord, N. C.

Sample Type Particulate

Run Number 1

Operator M. Y. Aldridge

Sample Box No. 1

Meter Box No. 1

Meter $\Delta H_@$ 2.37

C Factor 1.4

Probe Type Stainless Steel

Probe Length 5 ft.

Probe Tip Dia., In. 0.25

Probe Heater Setting 25%

Heater Box Setting 250

Assumed Moisture % 5%

Ambient Temperature 70°F

Barometric Pressure, In. Hg. 29.30

Static Pressure (P_s), -0.62 in. H_2O

Stack Dimension(s) 47.25 in. diameter

Distance: Disturbance to port 32 ft.

Distance: Port to exit 35 ft.

Reference Δp .55

Filter number(s) 121

Remarks:

Sheet 2 of 2

TRAVERSE POINT NUMBER	CLOCK TIME (24 hr CLOCK) / SAMPLING TIME, min	GAS METER READING (V_m), ft^3	VELOCITY HEAD (Δp_s), in. H_2O	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O		STACK TEMPERATURE (T_s), °F	DRY GAS METER TEMPERATURE		PUMP VACUUM, in. Hg	SAMPLE BOX TEMPERATURE, °F	IMPINGER TEMPERATURE °F
				DESIRED	ACTUAL		INLET ($T_{m\,in}$), °F	OUTLET ($T_{m\,out}$), °F			
	2:30 P. M.										
S 1	00	289.87	.42		.96	355	77	74	2.0	250	56
1	05	293.00	.40		.95	355	80	74	3.0	250	56
2	10	295.38	.47		1.1	355	82	75	4.0	250	57
2	15	300.01	.48		1.1	355	84	76	4.0	250	58
3	20	304.00	.46		1.1	355	87	78	4.0	250	60
3	25	307.30	.46		1.1	350	89	79	4.5	250	60
4	30	310.75	.55		1.3	350	90	82	5.0	250	60
4	35	314.57	.55		1.3	350	90	81	5.5	250	59
5	40	318.38	.57		1.3	350	90	81	6.0	250	58
5	45	322.24	.56		1.3	350	90	82	6.5	250	60
6	50	326.10	.56		1.3	350	90	82	7.5	250	61
6	55	330.00	.55		1.3	350	90	82	8.0	250	60
6	60	333.90	.55		1.3	350	90	82	9.0	250	59
	3:30 P.M.										

AQ-44

AIR QUALITY DIVISION

SOURCE SAMPLING F. D DATA

Plant Kerr Industries
Date January 24, 1973
Location Concord, N. C.
Sample Type Particulate
Run Number 2
Operator R. W. Buck, Jr.
Sample Box No.
Meter Box No.

Meter $\Delta H_@$ 2.37
C Factor 1.4
Probe Type Stainless Steel
Probe Length 5 ft.
Probe Tip Dia., In. 0.25
Probe Heater Setting 25%
Heater Box Setting 250
Assumed Moisture % 5%

Ambient Temperature 60°F
Barometric Pressure, In. Hg. 29.4
Static Pressure (P_s), -0.62 in. H_2O
Stack Dimension(s) 47.65 in. Diameter
Distance: Disturbance to port 32 ft.
Distance: Port to exit 35 ft.
Reference Δp .55
Filter number(s) 123, 124

Remarks:

TRAVERSE POINT NUMBER	CLOCK TIME (24-hr CLOCK) / SAMPLING TIME, min (1:00 P.M.)	GAS METER READING (V_m), ft^3	VELOCITY HEAD (Δp_s), in. H_2O	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O		STACK TEMPERATURE (T_s), °F	DRY GAS METER TEMPERATURE		PUMP VACUUM, in. Hg	SAMPLE BOX TEMPERATURE, °F	IMPINGER TEMPERATURE, °F
				DESIRED	ACTUAL		INLET ($T_{m\,in}$), °F	OUTLET ($T_{m\,out}$), °F			
E 1	00	347.20	.4		.95	355	63	61	2.0	250	54
1	5	350.50	.40		.95	350	68	61	3.0	250	48
2	10	353.78	.50		1.15	355	72	63	3.5	250	47
2	15	357.29	.50		1.15	355	74	65	4.0	250	48
3	20	360.80	.46		1.05	355	76	67	4.5	250	50
3	25	364.22	.46		1.05	355	77	68	5.0	250	50
4	30	367.63	.52		1.20	355	79	70	6.5	250	51
4	35	371.20	.52		1.20	355	79	70	7.5	250	51
5	40	374.76	.54		1.25	355	82	72	9.5	250	52
5	45	378.40	.54		1.25	355	83	72	10.0	250	54
	CHANGE TO FILTER #124										
5	45	378.40	.54		1.25	355	74	71	3.5	250	54
6	50	382.05	.47		1.10	355	78	71	7.5	250	50
6	55	385.66	.47		1.10	355	82	72	9.0	250	55
6	60	389.00	.47		1.10	355	84	74	11.0	250	58
	2:15 P.M.										

80

AQ-44

2-15-72

SOURCE SAMPLING FIELD DATA

Plant Kerr Industries
Date January 24, 1973
Location Concord, N. C.
Sample Type Particulate
Run Number 2
Operator R. W. Buck, Jr.
Sample Box No.
Meter Box No.

Meter $\Delta H_@$ 2.37
C Factor 1.4
Probe Type 55
Probe Length 5 ft.
Probe Tip Dia., In. 0.25
Probe Heater Setting 25%
Heater Box Setting 250
Assumed Moisture % 5%

Ambient Temperature 56°F
Barometric Pressure, In. Hg. 29.4
Static Pressure (P_s), -0.62 in. H_2O
Stack Dimension(s) 47.25 in. Diameter
Distance: Disturbance to port 32 ft.
Distance: Port to exit 35 ft.
Reference Δp .55
Filter number(s) 125, 126

Remarks:

TRAVERSE POINT NUMBER	SAMPLING TIME, min / CLOCK TIME (24-hr CLOCK)	GAS METER READING (V_m), ft^3	VELOCITY HEAD (Δp_s), in. H_2O	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O		STACK TEMPERATURE (T_s), °F	DRY GAS METER TEMPERATURE		PUMP VACUUM, in. Hg	SAMPLE BOX TEMPERATURE, °F	IMPINGER TEMPERATURE, °F
	2:30 P.M.			DESIRED	ACTUAL		INLET ($T_{m\,in}$), °F	OUTLET ($T_{m\,out}$), °F			
S 1	00	389.00	.30		.72	355	72	70	2.0	250	52
1	5	391.91	.30		.72	355	73	69	2.0	250	48
2	10	394.83	.39		.90	355	74	68	2.5	250	50
2	15	398.02	.39		.90	355	75	68	3.0	250	51
3	20	401.23	.42		.96	355	76	68	4.0	250	52
3	25	404.62	.42		.96	355	76	69	5.0	250	54
4	30	408.05	.52		1.20	355	79	70	6.5	250	52
4	35	411.61	.52		1.20	355	83	71	7.0	250	52
5	40	415.23	.56		1.27	355	84	73	8.5	250	52
5	45	418.95	.56		1.27	350	84	74	10.5	250	53
5	46	419.70	.56		1.27	350	84	74	10.5	250	53
	CHANGE TO FILTER #126										
5	46	419.70	.56		1.27	355	73	69	3.5	250	55
6	50	422.76	.56		1.27	355	75	69	5.0	250	54
6	55	426.45	.56		1.27	355	76	70	6.5	250	57
6	60	430.00	.56		1.27	355	77	70	7.0	250	60
	3:45 P.M.										